Fish By-Catch . . . Bonus From The Sea

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on Shrimp By-Catch Utilization held in
Georgetown, Guyana, 27–30 October 1981

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Preface

By the year 2000, world demand for fish as human food will reach an estimated 1.0×10^8 t annually, about double the amount used for human consumption in 1979. This increasing demand will have to be met by expanded aquaculture production and use of fish that are now going into animal feed or are being unintentionally caught by shrimping vessels and thrown away at sea — the by-catch. The single largest and most readily available resource is the by-catch of the shrimping fleet. The estimate is that $3–5 \times 10^6$ t of by-catch fishes are discarded every year, a truly colossal example of postharvest loss.

The recovery and utilization of the large quantities of heterogeneous fish species that are at present being wasted would provide an enormous quantity of animal protein to improve the nutrition of people in many areas of the world. With this in mind, personnel at the Fish Utilization and Marketing Service of the Food and Agriculture Organization of the United Nations (FAO) organized a technical consultation on shrimp by-catch utilization to prepare and start implementing a comprehensive and coordinated global action program aimed at the full use of the by-catch from shrimp-fishing activities. It is hoped that the publication of the proceedings will contribute to the efforts of making better use of food resources. The cooperation of the International Development Research Centre (IDRC), Canada, which provided assistance in the conduct of the consultation, funded the participation of several representatives from developing countries, and undertook to publish the proceedings, is gratefully acknowledged.

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Introduction

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The Ministry of Fisheries of the Government of Guyana was a gracious host to the technical consultation on the utilization of the fish by-catch from shrimp trawling, convened through the joint sponsorship of FAO and IDRC, in Georgetown, Guyana, 27–30 October 1981. The consultation was attended by specialists from 20 countries and 10 agencies, a total of 64 participants. Background documents and contributed papers totaled 33, presenting a varied experience in the recovery, processing, and marketing of fish by-catch in all the developing regions of the world.

The Guyana Fisheries Minister, Robert E. Williams, welcomed participants and the Agriculture Minister, Joseph A. Tyndall, in opening the consultation, indicated Guyana's policy of national self-sufficiency in food and the role of fish within that policy. Gratitude was expressed to the Food and Agriculture Organization of the United Nations and the International Development Research Centre as sponsors of the meeting. Representatives speaking on behalf of both organizations stressed the global significance of the consultation and thanked the contributors of papers and the participants.

It has been recognized for many years that vast quantities of potential food are being discarded at sea — the incidental catches of fish from shrimp trawling operations. The growing world food problem in developing regions and higher fuel costs have prompted many countries and agencies to consider ways of halting this waste and putting the resources to better use. Their efforts have been supported by agencies such as FAO, IDB (Inter-American Development Bank), IPFC (Indo-Pacific Fisheries Council), and IDRC. For example, IDRC supported an early project in Guyana (1973) and funded a symposium on stable fish products for human consumption (1974).

More recently, world and regional conferences have been held in Asia, Europe, and North America, in which various aspects of the use of by-catch fish have been addressed. Special technical workshops have been sponsored by IPFC and IDB. Currently, several other programs are actively operating in Colombia, Mexico, Nigeria, India, and Thailand, for example, where the fish are increasingly being retrieved for human consumption. There are, nevertheless, many problems to be overcome, and they clearly require a coordinated technical approach.

The proceedings of this consultation indicate that there is considerable existing technology, in laboratories of government and industry, capable of solving the problems associated with fish by-catch retrieval and processing. Exchange of expertise, training, and equipment modifications are needed in all areas associated with the problem. The maintenance of continuous information exchange and the eventual establishment of a coordinated program by sponsoring agencies and other interested bodies seem highly desirable. The various sessions indicate the critical areas for action to relieve constraints and apply proven technology.

The publications and films shown at the consultation demonstrated the widespread interest and increasing impact of the use of this available food source for direct human consumption. The potential is progressively enlarging, as new technical processes for food formulation are applied to underutilized species of fish.

The conservation of resources to feed the hungry is of concern to all, and the resources of the planet are fast diminishing, as vividly described in the Brandt Commission Report. The sea may well be the last frontier for significant food-production increases, and fish may well be the last major source for increased protein for a starving world. Cooperation in the effective use of the resources will be of immediate and continuing benefit both to this renewable source of food and to all humanity.

The summary of technical discussions and the final recommendations from the consultation, therefore, deserve the favourable attention of executive administrators, policymakers, and all personnel involved in fisheries development.

Summary

The problem of postharvest loss derives from the carrying capacity of the shrimp trawlers, reflecting design, size, operational system, and costs. The vessels vary in size (between 14 m and 20 m), but the most common design is about 15 m with refrigerated hold (capacity 30 t), powered by 450 hp engines, and equipped with twin trawls. The crew is four. These vessels are highly powered for their size and operationally designed for a payload of shrimp, the market price of which is generally more than 15 times the value of the fish caught in the trawl at the same time. The fish catch is also vastly more bulky, comprising a variety of types. Shrimp is an important foreign-exchange export commodity. For these reasons, it has been considered unprofitable to retain the fish during standard trawler operations.

The term by-catch refers to all the fish and other organisms incidentally harvested by the trawling operations. In the past, all the by-catch was discarded into the sea and only the shrimp retained. This practice resulted in high losses from the discards. Now, it has become increasingly common to select and retain some marketable fish. By-catch quantities are, therefore, no longer the same as the discards in every area where shrimp trawling occurs. Assessment is necessary for both the by-catch and the discards.

Assessing Postharvest Loss

There is wide variation in the by-catch yield not only by region but also by season within specific areas. This complicates the procedures for obtaining accurate estimates of the postharvest loss, which occurs in widely differing fish and shrimp communities of tropical and subtropical fishing grounds. To date, researchers have primarily relied on four methods for such estimates:

- Sampling catch for length/weight projections;
- Sampling discards for length/weight regression;
- Weighing total catch before discards; and
- Obtaining estimates of weight caught and discarded recorded in vessels' logs.

Data from research vessels together with computer adjustments for the various types of gear employed by the vessels of the fishery have been the basis for some estimates; however, in most regions, assessments have been made from commercial experience and captains' reports of marketable fish/shrimp ratios.

Current global estimates of by-catch vary between 5×10^6 t and 16×10^6 t, with a ratio of shrimp/fish of about 1 : 5 in temperate or subtropical waters and an average of 1 : 10 in tropical areas. There are a greater number of species of fish in the by-catch from tropical waters. Figures are cited in the papers in this publication for the waters of the south Atlantic–Gulf of Mexico region, Baja California, Guianas, and Malaysia. By-catch yield varies greatly with water temperature, current, bottom, and other ecological conditions. In some areas, estuarine outflows and lunar cycles cause variation in productive fishing locales from close to shore to far away. Where vessels make short trips and market demand exists, the discards of fish are smaller and selective. Vessels making long trips in less variable weather conditions give different by-catch ratios. In some areas, where the shrimp season is short, almost all the fish caught at the start of the season are discarded, although more fish are brought to market toward the end of the season when the shrimp catch per vessel declines.

Although the fish by-catch comprises many different species, a few species predominate consistently in most regions. The more common species seem generally to be lean-fleshed, predatory, demersal fish. Small fish make up most of the by-catch along the north Pacific coast of Mexico, whereas large marketable fish constitute the greater part of the catch of the Guianas. Generally, assessments indicate that between 24% and 69% of the fish are marketable species. In Mexico, for instance, the estimate is that trawlers in

nearby waters obtain 20% large, marketable species; 40% marketable species 14–25 cm long; and 30% smaller than 14 cm that are discarded at sea. In other areas of the world, however, the sizes of marketable species and of types for industrial use are rather different.

For assessments of the by-catch to have any valid meaning, the fish should be classed according to their potential market use, and market use should be based upon chemical analysis and flesh characteristics. The standardization of assessment methods for each region could be facilitated by a manual of procedures and the classification of major target species according to their potential market use (after analysis has determined this). Taking this approach is especially important for tropical areas where species and ecological conditions are diverse and staff trained to make assessments in population dynamics are few.

Only a few systematic regional studies have been made of the by-catch discards. A continuous record and complete analysis of data indicating changes of market species available throughout the seasons of the fishery are required as a basis for industrial use of the by-catch. Again, such assessments are most needed in tropical areas where the fish by-catch is particularly large.

Assessing the by-catch has important implications for biologic and socioeconomic considerations in the management of fisheries within exclusive economic zones. For example, the presence of major demersal species needs to be monitored because of their role as predators in the dynamic ecological equilibrium of the resource. The effects of inshore and estuarine operations need to be considered from the viewpoints of current and future investment, resource management, employment, and foreign exchange earnings.

Recovery, Handling, and Preservation Aboard Vessels

The contributors to the consultation recognized the recovery, handling, and preservation aboard vessels as the most critical aspect of the whole by-catch problem. The bulk, species variability, low value and marketability of the by-catch fish combine to make collection at sea unprofitable. Until these problems are efficiently and economically overcome, there can be no attraction for commercial recovery of the large quantity of fish available. Furthermore, recovery is only part of the process; the fish must be kept in good condition for processing ashore into edible products. A great variety of attractive, high-value products from the by-catch have already been demonstrated; therefore, the commercial practicality of using the resource depends ultimately on efficient recovery at sea.

The options for handling the by-catch involve:

- Presorting of the fish and shrimp during harvesting by means of separator or excluder trawls;
- Total collection of the catch with sorting done aboard the trawler for stowage or transfer at sea to collector vessels; and
- Partial processing of selected fish of the by-catch at sea.

The application of the first option would significantly reduce the bulk of fish harvested and the workload of the crew. The other two choices are applicable to areas where the fish/shrimp ratio is particularly high and where it is impractical to stow on board even the large marketable species of the harvest. Both of these options require additional crew so that the harvesting of shrimp can continue unhindered.

Incentives that will motivate crews to recover and handle the by-catch need to be studied. The first step, however, is a realistic assessment of the operational costs. The recovery of these costs plus some incentive may prove attractive.

Several types of trawls have been designed during the past 20 years to separate or exclude fish from the shrimp catch. Although positive results have been reported in many cases, commercial operations, generally, have not adopted the use of such trawls. Using electric currents in the water to exclude fish has also been tested. Because of the large quantity of fish in tropical waters, a device for separating the fish from the shrimp in the trawl before the catch is discharged on deck would be valuable. A suggested study on a presorting system using sound emissions to deter the fish from entering the trawl is proposed in this publication. The system would permit juvenile fish to escape capture, allowing stocks to rebuild and increasing the numbers of adult, marketable species available in the fisheries. One problem this approach does not address, however, is the shortage of food, especially protein sources, in many areas of the world and the vast quantity of potential food that is unutilized in the seas because it is in the form of small, demersal fish species.

To address this problem, one must recover the by-catch. In many places, this either is being done already or is being considered. In the North Sea, sorting and grading the catch is done, on board vessels, by a rotating sieve-like drum. The fish are separated according to shape and size — an operation that facilitates the sorting into species and storage.

A time-and-motion study on the quantities of catch, sorting, and stowage aboard vessels in Mexico's Baja California indicated that, in most cases, the cold-storage space on the trawlers operating in the fishery was adequate and the time available was sufficient for the crew to sort and stow the fish in the hold. However, without additional crew, time was not available to gut all the fish — a procedure necessary to ensure good quality. The constraint seemed to be financial — there was no economic incentive to bring in that part of the catch that could be readily handled. However, increasing quantities of by-catch are now being landed in this area.

In Suriname, French Guiana, Mozambique, and Thailand, fish are recovered during the last days of the trips to sea; they are selected according to market end-use. In Sri Lanka, where short, day-long fishing trips are standard, the shrimps are stowed on board and the fish by-catch is towed to port in nylon netting bags alongside the vessel. The fish are then separated on shore for industrial use.

The options for transfer of catches at sea present a series of problems involving the coordination of fleet operations for rendezvous with collector vessels and the methods for ensuring the quality and identity of catches from trawlers. The problems are compounded by the fact that many captains carefully guard as secret the locales in which they have the greatest shrimping success. Although frozen shrimp in sacks are regularly transferred in some fishing operations in Guyana, the much greater bulk of the fish by-catch poses problems for rapid transfers at sea in all weather conditions.

The main concern of captains and owners appears to be that the valuable shrimp catch will be spoiled by rising temperatures in their small refrigerated holds provoked by the bulk storage of fish. One way to alleviate this concern is to rationalize the current fleet into vessels specifically for shrimp or fish. The approach of using chilled seawater (CSW) in containers has been taken in Chile and has resulted in improved-quality sardines in the purse-seine fishery there. Other means are to separate the shrimps and fish in stowage and to reduce the bulk of the fish by partial processing — mincing, for example — on board. The costs of operating collector vessels and of refrigerating or icing the bulk of the fish make use of collecting systems impractical in many places — for instance, Colombia — because the market value of the by-catch is low. For one thing, in the fresh or frozen state, by-catch fish cannot compete with better-known, well-established species; they must be processed for human consumption if they are to have increased market value. This is the aim of projects in Guyana, Mexico, and elsewhere.

Mechanical separation of fish from shrimp and partial processing of fish to reduce bulk and convert them to mince, silage, etc. would permit storage aboard the vessels in current use. The replacement of old vessels with those of new design, with larger hold capacity, would also alleviate handling and recovery problems. A combination of such solutions will probably be the most appropriate approach for different fisheries. No standard design for vessels is likely to be applicable worldwide because of the problems peculiar to each area.

Processing on Shore

Industrial research in the field of fish processing and product development has resulted in many innovative methods and formulations using fish as an ingredient for human food. The fish products are even more varied and far-reaching than poultry or meat products. The versatility, which derives from the great diversity of fish species, contributes to efforts to produce high-protein foods, both low-cost and high-value specialty types. The high-protein wastes can be used in livestock feeds.

Recent advances involve new machinery, systems, and products. The main motivation for the work that has been done so far is the desire to increase food supplies and alleviate hunger by appropriate and profitable techniques for preserving and processing multispecies fish harvests. It is essential to take into account various food habits in regions where by-catch is available and to select suitable and profitable processing techniques on the basis of market information. Differences in the nature of by-catch in different regions may also dictate the types of process required. For example, in regions where by-catch comprises many commercial fish, ways of extending traditional processing schemes to include by-catch should be sought. Where the by-catch is predominantly small, noncommercial fish, less-conventional techniques that yield new products or simulate existing items are normally required.

Minced, deboned fish muscle is the basic, most versatile and easily produced material from the small species in the by-catch. A variety of existing and innovative food products can be manufactured from it, and new uses keep appearing. By-catch fish fillets also have potential, and mechanical deboning of the frames promises to increase the product range and profitability of filleting operations. Clearly, much progress has been made in the development of dried and salted, frozen, surimi–kamaboko-type, and canned products both from whole and filleted by-catch fish and from deboned minces.

Efficient evisceration and deboning of the small fish are major problems. Gutting the fish by hand produces appreciable quantities of waste and is time-consuming. However, preliminary studies suggest that soaking the fish in acetic-acid solutions shortens the evisceration time considerably and does not adversely affect the product. In the case of deboning, the selection of suitable machinery that will not allow contamination of the mince with fine bones and scales is particularly important. Further development work on equipment design is essential.

Acceptability tests have shown that minced products developed from by-catch are well received by people in several regions. Low-cost, nutritious, and tasty, these include fish chips, noodles, balls, croquettes, salami-type sausages, dried soups, and jellied fish products. Frozen fish sticks are also showing potential, particularly as children's food. Washing techniques for clarifying by-catch minces have been described and may prove beneficial in generally standardizing the properties of minces prepared from different species mixtures. Deboned by-catch minces may be used as raw material for canned products, such as pâtés and sausages, intended to simulate meat products already existing in the market. Moreover, by-catch from Asian waters has been successfully converted into frozen surimi and fish-jelly products. All the techniques, which demonstrate the versatility of by-catch minces, have reached the commercialization stage, and, in most cases, some industrial production is either planned or under way.

Areas of activity for further investigation and promotion include:

- Improvements in the texture of minced products;
- The design of improved and less-expensive equipment for by-catch processing, particularly efficient evisceration and deboning machinery for small fish species;
- The possibilities of simulating more of the products currently on the market;
- Comprehensive evaluation of the flesh characteristics, including biochemical and functional properties, of by-catch fish harvested in different regions;
- Development of techniques for manufacturing acceptable infant foods incorporating minced fish;
- Development of techniques for use of fatty fish as minces and products for direct consumption; and
- More detailed consideration of economics of processing and marketing aspects of by-catch products.

Actual and Potential Markets

Two general types of market may be defined — the economic market, serving consumers with purchasing power, including institutions, and the noneconomic market, catering to the vast majority of people in developing countries whose incomes are low, including those at subsistence level. It is essential to obtain profiles of the consumers within both markets in different regions; these profiles should incorporate information on food habits so that they can serve as the basis for development, packaging, cost characteristics, and distribution techniques for products from the by-catch. Regional information systems, such as INFOPESCA (Latin America) and INFOFISH (Asia), could undertake the task of retrieval and processing of such data along with other information appropriate to the marketing of by-catch products.

A number of marketable products have already been formulated at the laboratory-, pilot-, and industrial-production scales. The products can be classed as food (direct consumption), livestock feeds, and industrial by-products. Many of these products are attractive to existing markets; others are intended to cater to potential markets of increasing importance.

Processed forms that are a mix of traditional products and that can be readily incorporated into customary food preparation, as well as small amounts of new, convenience products are especially promising. Yet, even these forms require promotion. One method is to hold demonstrations and exhibitions, which familiarize consumers with the product and provide feedback to the processors. The largest market, at present, seems to be institutional outlets. Low-income groups in both rural and urban districts are also an important target; however, these groups have conservative food tastes and, hence, are difficult to reach. Market surveys and consumer-acceptance studies of innovative products are essential, and efforts to promote products probably need to be diffuse as well as diverse. To reach the low-income target, one may have to reach higher-income groups.

For a profitable mix in industrial manufacture of fish products, experience indicates that it is desirable to introduce higher-cost specialty products intended for high-income urban populations, fast-food restaurants, hotel outlets, etc. Sausages, surimi-type fish pastes, and other products derived from minced or jellied by-catch fish have been successfully introduced into several markets and have had increasing consumer appeal.

The processed by-products from deboning machines and trimmings from traditional processes have been made into fish meal and bone meal for livestock feeds, as well as fertilizers. Less capital-intensive processes such as the production of fish silage have also been well promoted in Asia for small-scale, livestock-meal preparation. Increasing local demand for such feeds can be satisfied by the residues from food processing, even though this source would not be competitive in international fish-meal markets.

Other products from by-catch species for which markets are growing include shark fins, shark leather, shark teeth, fish scales, and glues as well as chitosan from the shells of shrimp. In addition, processing of the small species into foods for pets provides a higher return than reduction to fish meal. Specialty-market outlets are developing in some areas for small cocktail shrimp, for mixtures of species to make soups, and for smoked and pickled products of lesser-known seafoods.

Maintaining standard quality, strict hygiene, and attractive presentation for all new products is essential, but not sufficient, to ensure good market acceptance. It must be accompanied by careful assessment of competing items, commodity-price levels, characteristics of the market, distribution systems, produce-packaging requirements, purchasing power of various levels of the community, etc. Professionally done, surveys of these aspects will provide the key to successful marketing.

Steps required before new products are launched into the market include: acceptability studies for urban and rural consumers; product promotion through the media; and product demonstrations that show the value of the product to the consumer. At present, lack of adequate market infrastructures and of marketing expertise is inhibiting progress in many regions. However, some market studies on by-catch products, including minced fish, have been carried out in several countries, and some success has been achieved in promoting the products to the consumer. In particular, school-lunch schemes and other institutional programs have been appropriate initial targets for processed, minced fish. "Selling" the product to these programs provides not only a current market but a future market, familiarizing children with the products and providing them with protein at a critical age of development.

Still, there is a need to improve and intensify market studies for both the economic and the subsidized markets. A systematic model could be used as a guide and could be modified for use in different regions. The CARICOM (Caribbean Community) study on fresh fish and fish products in the Caribbean region may prove valuable in this regard.

Economic Aspects

The major obstacle to the utilization of by-catch fish for human needs is the profitability of the operation, both for individual boats that furnish their catch to processing plants and for totally integrated activities involving a fleet, processing, and marketing operations. Therefore, assessment of the potential and actual quantities of by-catch available as well as the methods of handling and processing has to be accurate if one is to determine procedures that will make operations profitable. In many cases, estimated costs of production have not been realistic because the costs of vessel operations are not fully known. Without this information, it is impossible to devise incentive strategies that induce shrimpers to land the by-catch.

Clearly, suitable techniques for recovery and processing will become established industrially only when they are proved to be profitable. In this context, the case studies of the Guyana and Mexican industrial experiences as well as proposals involving an industrial profile for dried, salted, minced fish and a small fish-meal plant for batch processing are especially noteworthy. In regions where by-catch of commercial size is available, the most financially viable approach is to produce fresh, frozen, salted, and smoked items for which a market traditionally exists. This is the approach that served as the basis for plans to expand processing operations in Guyana to increase by-catch utilization. In this case, no investments are made for products that do not have an established marketability. This includes food products as well as fish meal made from wastes.

However, where by-catch comprises predominantly small fish, processing into deboned minced products represents a feasible means of utilizing the bulk of available fish for direct human consumption. Industrial operations for minced fish processes, specifically applied to by-catch, have been designed in Mexico and shown to be financially viable. Moreover, it is possible to produce competitively priced items, which may simulate meat or fish products already available in the market, from by-catch fish. Implementation of industrial projects for minced fish production is currently in progress in Mexico, and a minced-fish plant, using by-catch as raw material, has operated successfully in Colombia for the past few years.

To achieve economically viable use of by-catch, processors must pay an attractive price to the shrimpers for landing the raw material and must manufacture acceptable products at a competitive price. These requirements may conflict in some regions, and government intervention, such as legislation and initial price subsidies, may be necessary to facilitate by-catch utilization.

Nevertheless, the economic feasibility of processing by-catch into human food is attested to by the growing interest on the part of private-sector investors. To further such interest, a government-sponsored demonstration plant is being installed in Mexico. This could serve as a regional model for processing by-catch into a variety of minced-food products, whereas the Guyana plant could represent a model for manufacturing a range of more traditional products from by-catch.

Recommendations for future action in this area include:

- Comparison of operational costs of boats and by-catch recovery systems in different areas under actual working conditions of shrimp vessels to determine the cost–benefit of processing different by-catch species and mixtures for specific target markets;
- More detailed consideration of the socioeconomic aspects of by-catch utilization;
- Further examination of the energy requirements for by-catch recovery and processing systems;
- Development of viable institutional schemes to distribute foods in the noneconomic market; and
- Implementation of a broad scope of action to include financing, investment, and market analysis as well as technical assistance and industrial training of personnel for processing plants.

Regulatory, Legal, and Monitoring Aspects

Regulations that exist in some fisheries and those likely to be introduced can profoundly influence by-catch utilization and even its availability. They have not been addressed adequately in the literature, and they are only tentatively approached in this publication, as governments are still seeking guidance in the introduction of management measures. In the Gulf of Mexico, as in most long-established fisheries, there are controls on seasons and mesh sizes and requirements for collection of biostatistics. As a result of the extended fisheries jurisdiction that has been recognized since mid-1970, some coastal states now place observers for data collection aboard foreign vessels in their waters. However, few developing regions have such regulatory measures, and data collection from all vessels fishing in these areas is important. As a first step, governments should consider uniform mesh sizes and close seasons for specific fisheries. Shrimp-trawling operations and estuarine and artisanal operations have different impacts on the resource and should be treated separately in decision-making about management measures. Different zones for such operations are potential management tools and may be particularly advantageous if considered from a socioeconomic viewpoint.

In general, a better understanding of the amount, sizes, and species composition of the by-catch is required. Fuller utilization, such as is now being promoted in Guyana and Mexico, should be encouraged, but more complete data are needed as a background to regional resource management. In areas where development of a groundfish industry is a possibility, efforts should be devoted to the study of mesh sizes and the design of an efficient standard.

FAO fisheries commissions should play a prominent role in harmonizing regulations, data collection, and interpretation. It would be especially useful if the commissions would determine whether there is any evidence of population changes owing to selective cropping of the resource by the removal of shrimp and the effect of the discards. It would also be valuable for them to demonstrate that, although shrimp have an annual life cycle, a mesh size of net that allows the escapement of juvenile shrimp and fish produces optimum yields of shrimp.

Fishing intensity should be regulated by coastal states, particularly in view of the potential effects of increased fishing effort on groundfish stocks. Improved knowledge of seasonal changes in by-catch ratios, by-catch composition, and shrimp landings should lead to the development of management measures based on seasonal closures. In most regions, the present intensities of shrimp fishing are too high and are wasteful of the limited economic resources. Profitability is only possible at lower overall levels of fishing effort than are currently in effect.

Thus, careful examination of the management objectives of the shrimp fisheries is recommended, not only so that the optimum economic level of shrimp fishing can be defined but also so that survival of by-catch fish to commercial size can be encouraged.

Another aspect of regulations is product standards and quality control. The use of minced fish products for human consumption requires further attention. The development of quality standards for by-catch products is problematic because of the diversity of fish species constituting the resource. To eliminate or avoid unnecessary legal barriers to by-catch utilization, developing countries should consider the product and its characteristics as the point of control and not the identification of individual fish species from which the mince is prepared. At present, the USA, Canada, and to some extent Japan all have regulations that prevent the use of mixed species in processed items, although the rationale for such controls is questionable. The Codex Alimentarius should be revised such that regulations are based on the wholesomeness and sanitary quality of products. The nomenclature for the raw material and the products should also be standardized, especially when cited in the reports of international organizations and in regional communications by scientific institutions and the fishing industry.

Using only the flesh of fish in the production of minced products reduces the risk of accumulation of toxic heavy metals that are concentrated in bones. Thus, the problem, experienced in many fisheries where whole fish are marketed, is lessened where minced flesh is the marketed product. Also, the removal of poisonous species before processing the catch is essential.

National and Regional Developments

Activities on by-catch utilization are progressing in diverse regions of the world. The geographical area of most varied activity is the Gulf of Mexico and Latin American countries. Nevertheless, in West Africa, the Indian Ocean, the South China Sea, and the Indonesian seas, the problems of by-catch retrieval and processing are also being investigated. Industrial developments in Nigeria and India have been cited in the bibliography but were not discussed in detail at the consultation because the representatives from these countries were unable to attend.

Some countries have established forms of industrial exploitation of by-catch, whereas others have not yet developed viable solutions. A few countries have established centres for research and development studies on by-catch for their region. Practical recovery of by-catch appears to be more problematic in some countries than in others because of the complexity of the organization of the shrimping industry.

There is urgent need for cooperation and a much wider exchange of information on experiences from the different regions. Furthermore, regional and international organizations with expertise in the field should increase their training input to those countries requiring assistance. The formation of a regional, or even global, program on the topic would be a useful step in promoting increased recovery and processing of by-catch efficiently, safely, and economically. For the portion of the catch that cannot be consumed directly by human populations, conversion to livestock feeds is one processing option.

Animal feeds

In some cases, the use of whole fish as feed for poultry production may be an equally, or even more, efficient means of converting by-catch into human food than methods to make the by-catch edible because of the appreciable waste that normally occurs during the manufacture of fishery products. This approach may be particularly applicable to the smallest fish in the catch.

The appropriateness of different processing techniques for animal feeds from by-catch is an important consideration. The relative advantages and drawbacks of fish-meal and fish-silage production should be fully appreciated. In general, fish meal has a wider market among livestock-feed compounders, but the processing equipment is usually designed for large volumes of raw material and is expensive. Liquid fish silage is more difficult to handle, but capital and operating costs of processing equipment are low, and the process is so versatile that any quantity of fish waste may be used as raw material. Comparative financial analyses of silage and fish-meal production should be carried out in different regions.

Experience in Mexico has demonstrated on a pilot scale that silage may be prepared from material rejected from by-catch processing plants, i.e., evisceration and deboning wastes. Good growth rates have been observed in pigs fed silage made from by-catch. Studies in Thailand have confirmed the efficacy of silage prepared from small by-catch fish as a supplement in pig and poultry feeds.

The distribution and sale of silage are difficult because it is a liquid feed that may vary in composition. Solar drying of silage–cereal mixtures may be appropriate in some regions as a means of providing a more easily transported component feed but requires further investigation. Fish silage appears most suitable for use by farmers who formulate their own feed mixtures.

Conclusions and Recommendations

Fish by-catch has long been a matter of great concern in the Indo-Pacific. Even greater attention has been focused on it since the 1973 FAO fish-products conference in Tokyo and the 1974 IDRC stable fish products workshop in Bangkok. There have been a number of projects in Asian countries aimed at better utilization of such fish, both for human food and silage. The Indo-Pacific Fisheries Council (IPFC) held a symposium on the use of the by-catch as fish silage processed by small village units, but the question of how to manage and promote the by-catch for human consumption is still largely unanswered in this region. There are vast quantities of by-catch in the South China Sea, the Bay of Bengal, and the South Indian Ocean, from shrimping operations adjacent to the most densely populated countries. This fact underlines the need for a coordinated program of action with outside assistance to promote the advances made in Thailand, Singapore, India, etc. Already the Southeast Asian Fisheries Development Center (SEAFDEC) in Singapore has undertaken an industrial approach to the use of the by-catch, and countries throughout the region should keep in touch with developments there.

In Africa, some attempts to use the by-catch are under way in the West, but little has been done to date in the East. Not only would information exchange be helpful to the researchers in this region but an interregional action program for industrial training and product development seems urgently necessary.

In Latin America, the use of by-catch is considered a particularly appropriate subject for international cooperation because the advanced technology for processing the fish resides in industrially developed countries, which are the main importers of shrimp, and the fish resources are needed chiefly for food in the developing countries whose waters contain the resources.

The view from Europe is that the techniques for retrieval and processing of by-catch already exist in European laboratories of government and industry. It remains to organize, through bilateral and multilateral channels, the exchange of expertise, the introduction of training, and the modification of equipment to effect a setup suitable to other areas of the world.

The representative from the ACP (African, Caribbean and Pacific) Secretariat has indicated that commercial use of the by-catch for human food is an ideal project for North–South interchange and that the ACP Secretariat could use its offices to facilitate small projects among its member countries and disseminate information in collaboration with technical agencies.

Both FAO and IDRC are urged to maintain a continuing information exchange and to encourage the momentum of interest until a coordinated program of action is under way. Participants at the consultation resolved that a task force involving FAO and IDRC be constituted, drawing on expertise from interested agencies, to formulate specific components, of action-oriented, coordinated support in a presentation to funding agencies.

To facilitate such action, a small ad hoc committee of participants subsequently drafted the outline of an "umbrella program," indicating support for specific projects, technological studies for commitment of host-country laboratories, and a possible geographic sequence for supported industrial activities.

In regard to the conclusions and recommendations of each session, it was agreed that economics and profitability are the areas where there are the major constraints to use of fish by-catch. The single most important constraint is the lack of methods to bring the catch to shore at a cost compatible with market end-use. Further, the training of personnel in successful, appropriate methods is much needed.

Participants drew up a logical sequence of technical studies rather than a list based on funding priority. They emphasized the overriding importance of education and training of personnel as being clearly essential in every aspect of their recommendations for action. They called for studies on:

- Harvesting techniques involving gear, sorting and storage systems aboard vessels, and the use of collector vessels servicing trawlers of traditional design;
- Vessels of new design for fishing in specific zones, such as "shrimp only" or "fish only" zones of fishing;
- Resource management and data collection and analysis of all trawlers fishing the resources, with classification of fish species available in the catch at all seasons and locales;
- Flesh characteristics of abundant and low-market demand species of fish coupled with product-development tests for varied markets and target populations (both low-cost and high-value specialty products);
- Design of simplified processing equipment for products suitable for small, batch rural plants and efficient large-scale industrial processing;
- Quality control standards and storage systems suited to local, regional, and export markets;
- Fish minces, including the use of oily species; and
- Plants for preparation of by-products and waste conversion to fish meal or fish silage for livestock feeds.

Specific recommendations were that researchers, funding agencies, and government organizations:

Methods

- Establish methods and standards for sampling, data collection, and assessment of quantities and species present in the by-catch, with FAO developing a manual to assist in this endeavour;
- Establish recommended gear standards as well as fishing zones for artisanal and industrial fishing activities;
- Establish guidelines to preserve the by-catch on board;

Data Collection and Dissemination

- Collect and disseminate harvesting data from all vessels fishing in defined fishing areas and analyze the information through special working parties of FAO fishery commissions;
- Establish regular exchange of information between countries where the resource is being fished;
- Facilitate access of developing countries to major information-storage centres;
- Collect and disseminate data about food products already on the market that could be amenable to the incorporation of fish minces or other products from the by-catch;
- Standardize the terminology and vocabulary of by-catch-related activities for clearer and more useful data and information collection and dissemination;

Special Studies

- Study the advantages and disadvantages in operating separate groundfish and shrimp fleets (rather than single boats) and operating small, less powerful and faster, fishing vessels;
- Produce economic profiles of pilot and commercial operations for the utilization of the by-catch;
- Conduct comparative studies of harvest transfer-at-sea systems already in operation and determine advantages and disadvantages of such procedures;
- Conduct total systems analyses of by-catch utilization in different regions, where there are differences in food preferences, economic constraints, levels of technological sophistication, availability of energy sources, etc.;
- Study the feasibility of partially processing the by-catch at sea;
- Assess available gear and equipment used worldwide for handling and processing of the by-catch;
- Investigate the composition of by-catches harvested in different regions and at different seasons to determine whether minces prepared from mixed-species catches can be analyzed to reveal their species composition; which, if any, of the species might represent health hazards; whether the regulations on mixed-species products in certain countries should be disregarded, at least for the time being, in view of the urgency of the need for food (these investigations should be initiated

without delay with the assistance and under the supervision of the Codex Alimentarius, FAO, WHO, etc.); and whether, and under what conditions, mixed species (processed or unprocessed) may be used in the manufacture of foods for international trade (what are the attitudes of agencies such as the U.S. Food and Drug Administration, the Canadian Food and Drug Directorate, the Japanese Food Regulatory Agency, etc.?);

Product Development

- Design techniques for small- and large-scale production of low-cost, stable, and nutritious foods from the by-catch, appropriate for consumption in different rural, institutional, and urban settings (priority to be given to dry, stable fish products and institutional foods suited to school-meal programs);
- Develop and test infant foods containing minced fish products;

Profitability and Market Studies

- Conduct product acceptability surveys for local, regional, and international trade, with emphasis on discovering food customs and taboos that would exclude the use of certain species of fish;
- Develop market intelligence and product-promotion strategies;
- Study product profitability, particularly for species that have a low market demand;
- Develop incentive schemes to encourage trawler crews to land the fish by-catch;
- Develop regional and national product-distribution systems;
- Conduct comparative studies of the operative costs of shrimp vessels' sorting and recovering the by-catch in different fishing grounds and climates;
- Compare energy consumption as well as operating costs and profit margins for the harvesting and processing of different species, for different products destined for different target markets;
- Study the social and economic impact of the use of the by-catch — for example, the effects upon the livelihood of those involved in artisanal fishing;

Training and Education

- Intensify efforts to train personnel in techniques of by-catch preservation, handling, processing, packaging, distribution, etc.;
- Introduce intensified training in quality-control monitoring of every step in the chain of activities from harvest to sale of the processed product;
- Develop strategies to provide developing-country technicians and researchers with training;

New Equipment and Processing Techniques

- Develop, design, and test, at sea, nets, escape-chutes, and other devices for selective capture of fish, particularly means to permit juvenile fish to escape capture;
- Redesign fishing vessels so that harvests can be stored in chilled seawater;
- Develop, design, and test methods for mechanical sorting and grading of the catch;
- Develop, design, and test equipment suitable for local construction and small rural- and industrial-scale, batch processing.
- Develop, design, and test energy-conservation equipment such as combustion engines fueled by alcohol, solar dryers, exhaust-heat systems for the manufacture of traditional fish products, and sail-assisted fishing vessels;
- Develop, design, and test equipment capable of heading and gutting small fish (10 cm) on board and on shore;
- Develop and test techniques to improve the textural characteristics of minced fish products; and
- Develop and test equipment and techniques to process fatty species of fish.

Background

Utilization of the Shrimp By-Catch

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General information is available on the abundance and composition of the shrimp by-catch, but information on specific geographical areas is still lacking. Information on the western–central Atlantic fisheries is rather complete, as is that for the Gulf of California. Researchers need to take a systematic approach toward obtaining data elsewhere, not only defining the composition of the catch but also developing handling, processing, and marketing techniques. Such information is essential if policy-makers are to delineate priorities for future work and to introduce incentives for personnel in the shrimp industry to value the by-catch. At present, the industry is built around shrimp, and neither the system nor the philosophy is broad enough to accommodate the handling of lower-valued species.

Government policies directed toward full utilization of the resource and economic considerations will be important factors in creating an environment for change. An integrated, systematic approach in studies of economic feasibility and investment analysis as well as training and modification of the infrastructure will be required.

In the Gulf of Mexico, United States shrimp-industry plants and ports are not equipped to handle the by-catch, and U.S. researchers maintain that processing alternatives are not economically attractive for shrimp producers. They suggest that the by-catch would be more appropriately handled by an industry already harvesting migratory species and groundfish. Labeling and food laws hinder by-catch use in the United States. Reports from other areas have been more optimistic. Mexico, Colombia, Guyana, and India are now actively involved in utilizing some of the shrimp trawlers to catch fish on a commercial basis; however, these countries note that shrimp trawlers do not have the capability to fulfill the goal of handling the by-catch satisfactorily and that future shrimp trawlers should be designed differently. The use of collector boats, with adequate refrigeration and processing equipment, has been recommended as a possible solution to the problem of handling the fish on board. When the by-catch has been landed, the technology available for utilizing it includes methods to produce silage, fish-protein concentrates, minced, frozen fish, and dried or salted fish products, etc. However, the economics of using a particular technology vary according to consumer demand in a region, as well as the availability of skilled personnel. Marketing potential is best for large food fish that have been well cared for on the boat and sold fresh or frozen. Smaller species, too, have potential for human food, and capitalizing on this is where the major challenge lies. A number of products are technologically possible, but few are finding consumer acceptance. Some promising work is being carried out on salted, frozen, and canned minced products. The principal markets for the shrimp by-catch appear to be domestic. The obstacles to foreign markets include transportation costs and criteria of receiving countries.

Research on utilization of the shrimp by-catch should include comprehensive regional studies that take into account the infrastructure. Based on these studies, and the composition of the by-catch, it will be possible to outline procedures for production of fresh, frozen, dried, smoked, canned foods or animal feed. Comprehensive product technology and marketing studies are also recommended as a basis for developing markets.

In 1980, FAO estimated that by the year 2000, the annual demand for fish and shellfish as human food would be double the 1979 level (about 5.0×10^7 t). At present, annual production of all fish and shellfish has leveled at about 7.0×10^7 t — about 5.0×10^7 t for human food and the remainder for animal feed. With rising costs in production and government schemes to conserve fishery resources, it is unlikely that global production will change much. The implication, therefore, is that increases in demand for seafood will have to be met by other means — aquaculture, for example. Fish that are at present used for animal feed or those that are thrown away at sea as the shrimp by-catch are also sources for increased supply. Using the fish flesh wasted during filleting is another option, as is using extenders such as vegetable or meat products. None of these developments is likely to be a panacea. Instead, developments will probably occur on many technical and economic fronts to make effective use of fishery resources and present them in forms that will satisfy consumer requirements.

Within this context, the shrimp by-catch deserves special attention.

Resource Abundance and Composition

World estimates of the quantity of shrimp by-catch available vary widely and are based on approximations of the ratio of by-catch fish to shrimp found in different geographical areas. Most estimates are based on a ratio of 5 : 1 for temperate waters and 10 : 1 for tropical waters. A report by the U.S. National Academy of Sciences (NAS) estimates shrimp by-catch to be 5–21 $\times$ 10^6 t/year. An FAO round table on expanding the utilization of marine fishery resources for human consumption, held in 1975, estimated that 3–4 $\times$ 10^6 t of fish by-catch from shrimping were discarded each year. In 1980, FAO estimated the total shrimp by-catch to be about 5 $\times$ 10^6 t. A conservative figure is 3–5 $\times$ 10^6 t/year.

Global statistics on the quantity of shrimp by-catch have little meaning to fishing personnel in different regions. Of particular significance, however, is the amount of by-catch in a particular fishery and the composition of the by-catch.

The availability of by-catch and the by-catch/shrimp ratio are influenced by geographical region, fishing area, and season of the year. In an FAO study on prospects for by-catch utilization in the gulf area of Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, the shrimp by-catch was estimated to be about 3 $\times$ 10^4 t in 1979. Revival of the shrimp industry and intensive development of demersal trawling should increase the by-catch to at least 7.0 $\times$ 10^4 t/year.

The western–central Atlantic fisheries region (WECAF) and Latin America have been the focus of intensive investigations on the quantity and composition of the shrimp by-catch. R.H. Young, in his review for FAO, noted the lack of information regarding the size and nature of the shrimp by-catch in the region. Only in the Gulf of California, Gulf of Mexico, and in the coastal areas around Guyana have the yields and biologic characteristics of the by-catch been systematically studied. The limited information available indicates that the nature and the abundance of the by-catch vary widely in different areas. For example, in the Gulf of Mexico, the ratio of by-catch/shrimp (19 : 1) for the north central Gulf is more than double that for the northeastern Gulf. Similarly, the by-catch found off the Guianas varies widely in quantity among different areas but averages an unusually high ratio of 20 : 1. In Pacific waters off the coast of Mexico, the by-catch/shrimp ratio varies from 1.3 : 1 to 33 : 1 with an average 6 : 1 for commercial purposes.

The wide variability in the estimates indicates that the information available is only sufficient for general planning purposes; however, the figures do provide some basis for an appraisal of the possibilities for by-catch production (Tables 1–3).

Most of the by-catch is demersal fish, but the size and species composition vary within a region and from catch to catch. In studies of the Gulf area of Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, at least 200 species of fish were reported in the by-catch. Studies in the Gulf of Mexico indicate wide variability in production, the composition being about 100 species. Usually, however, 3–5 species make up about 50% of the by-catch, and 7–10 species account for 75%. The average fish in the by-catch in the Gulf of Mexico is about 17 cm long, weighing about 60 g. Most of the fish in the Gulf of Mexico by-catch weigh less than 0.5 kg. Large finfish are rarely caught and

Table 1. Production of shrimp and by-catch in major countries, 1978.

Country	Shrimp production (10^3 t)	By-catch (fish/shrimp, 5 : 1) (10^3 t)
India	201	1005
USA	192	960
Indonesia	139	695
Thailand	85	425
Malaysia	82	410
Mexico	67	335
Japan	60	300

Table 2. Production of shrimp and by-catch by continent, 1978.

Continent	Shrimp production (10^3 t)	By-catch (10^3 t)
Asia	714	3570
Africa	30	150
Oceania	19	95
Europe	178	890
North America	303	1515
South America	80	400

Table 3. FAO (1978) figures for shrimp landings from Caribbean Atlantic operations, with estimated (×5) discards of edible marketable fish (Allsopp 1980).

	Shrimp (t)	Edible, marketable fish (t)
Barbados[a]	110	550
Belize	13	65
Colombia	6130	30650
Costa Rica	1070	5350
Cuba	7600	38000
Dominican Republic	74	370
El Salvador	4224	21120
French Guiana	62	310
Guatemala	1581	7905
Guyana	3175	15875
Honduras	2343	11715
Japan	2720	13600
South Korea	1685	8425
Mexico	26110	130550
Nicaragua	4532	22660
Panama	8912	44560
Suriname	4105	20525
Trinidad	267	1335
Venezuela	3820	19100
United States	121652	608260

[a]Barbados' trade statistics.

constitute no more than 2.5% of an average trawl catch. Crabs are found in large quantities in certain areas.

The by-catch from shrimping vessels in the Gulf of California comprises about 87 species of fish from 43 families; 9 species account for 65% of the fish caught. The size varies from 6 cm to 65 cm, but the vast majority measure 7–13 cm, the mean length being 11.8 cm. The bulk of the fish weigh between 10 g and 50 g. The percentage of commercial fish in the by-catch from the Gulf of California is reported to be low (2–5% of the total by-catch). However, it should be noted that this does not constitute a greater area of production than the Atlantic coast for which results are very different.

Investigations off the Guianas indicate that the total number of different species in the by-catch is between 70 and 150. Marketable commercial species are reported to make up about 50% of the total by-catch, thus representing a distinct economic resource.

Data on the composition and size of the by-catch are limited. This problem is compounded by a lack of uniformity in defining what constitutes the by-catch. For example, in Mexico and the United States, the by-catch is defined as small fish generally not suitable for direct commercial use or food, whereas in Guyana all species harvested, including the large marketable fish, are included in the definition of by-catch. Therefore, a clarification and a standardization would be a first step in future programs. Such a classification must relate both to size and to market end-use.

The Shrimp-Fishing Industry

Since 1972, the world catch of shrimp has varied between 1.1×10^6 t and 1.5×10^6 t. The top producing nations are India, the United States, Indonesia, Thailand, Malaysia, Mexico, and Japan. The shrimp fishery is characterized by a large number of small vessels (less than 30 m long). In 1978, about 6000 U.S. vessels were used to harvest 1.9×10^5 t of shrimp, whereas Mexico's fleet of some 3000 trawlers produced about 6.7×10^4 t. In 1978, Guyana had a fleet of about 200 trawlers, but the number of trawlers has been reduced in the past several years. Most Guyana shrimp vessels have facilities to freeze the catch on board.

The unit level of production of shrimp vessels is low — only 30–50 kg/day in some areas — whereas the carrying capacity of a typical vessel (20–30 m) is 64–85 t of shrimp. The small vessels generally use ice for preservation, and the larger ones often use mechanical refrigeration systems. Vessels using ice stay at sea for up to 2 weeks, whereas those using mechanical refrigeration can stay at sea for several months but average 6 weeks per trip.

In recent years, the increases in fuel costs have had a significant impact on shrimp fishing. In the Gulf of Mexico, about 10 L of fuel is required by shrimp trawlers for each kilogram of shrimp landed. At present, fuel costs represent more than $2.50/kg of shrimp to United States' vessels. These figures indicate the importance of devising more efficient fishing methods and techniques for increasing productivity. Benefits from use of refrigeration on board need to be evaluated against the additional costs of operation and the overall financial yield from the product.

A basic consideration in the shrimp fishery is that the entire industry is built around shrimp. The absence of conventional fish-handling experience and equipment among shrimp producers discourages diversification. The wide differences in market demand, type of produce, and price between the shrimp and the by-catch complicate attempts at integrating the two.

Social and labour considerations are also important. Because of the large number of small fishing units, it may be difficult to obtain the leadership needed to force technological change. However, integrated operations between the vessel operator and the market may be adaptable to innovation.

Utilization

Possibilities for utilization of the by-catch are influenced by the structure and nature of the fishery, as well as the industry's ability to apply technology and create a product that has demand in the marketplace.

A number of reviews have been written about the utilization of marine fishery resources, and many of the principles apply also to shrimp by-catch. In assessing the possibilities, one has to look realistically at the constraints resulting from the economically important activity — shrimping — and the economic incentives needed to bring about a change.

Handling on the shrimp vessel

The amount of by-catch landed after 3 or 4 hours of trawling can vary from as little as 25 kg to several hundred kilograms, depending on the particular fishery. The sorting of the by-catch can be carried out by hand in 30–60 minutes. In large catches, rotating devices or water tanks can be used to separate the fish from the shrimp. A rotating grader has been used on large North-Sea trawlers and could be adapted to the handling of shrimp by-catch.

The large, marketable fish can be gutted and stored in boxes of ice or frozen on the vessel for processing ashore. Some degree of order can be achieved if the fish are placed in plastic bags prior to being frozen. The larger the quantity of marketable fish present, the greater the opportunities for economic success.

The small fish — usually the bulk of the catch — are the ones that present difficulties. If they are to be used for fish meal or silage, they may be handled without ice for overnight trips. The use of refrigerated seawater for preservation may be possible, but it introduces another processing step for the crew and may not be feasible for a high-quality product. The reduction of fish into silage on the vessel is difficult because this procedure requires the handling of acid. Fish-meal production is not practical because of the large amount of space taken up by the fish-meal equipment and the questionable economics of using special equipment for the by-catch. Likewise, partial processing of by-catch into minced products or fillets is not practical on existing shrimp vessels because of space limitations and the increased crew required. The economics of such operations on large vessels, however, need to be evaluated in light of the relatively low catch rates of shrimp in most areas.

Factory-processing collector vessels

The concept of using factory-processing vessels for utilization of the by-catch has been put forth by a number of experts in this field. These vessels include facilities for freezing, filleting, mincing, and processing into fish meal and silage. If they were also equipped with facilities for heading and grading the shrimp, they could process the entire catch from a shrimp trawler.

An integrated operation similar to that used for transferring cod ends from fishing vessels to factory ships for processing is promising. In some areas, small motor vessels could serve as "runners" between the factory vessels and the shrimp trawlers. Integrating the operations would improve the economics of the shrimp vessels by reducing fuel-consumption costs and time involved in transporting the catch to shore. Also, improved quality of shrimp and by-catch is a possible side effect.

Technical and economic considerations

Generally, the higher the economic use for a product, the greater the incentive that is passed along from processor to producer. Thus, efforts should be directed toward taking advantage of the market. For example, in many parts of the world, fresh fish demands a much higher price than frozen — a fact that should direct the prime species to a fresh-fish market. In addition, traditionally processed products such as salted, dried or smoked fish have established, lucrative markets in some parts of the world and should be priority items for the by-catch in these areas.

The by-catch could also be used in other high-valued products, if procedures were introduced on the vessels to ensure high-quality raw material. A number of investigations have suggested that the by-catch can be minced and marketed frozen, salted, canned, or in combination with soybean or other products. Pastes and spreads have been satisfactorily prepared from a wide number of minced fish products, and cooked sausage as well as other simulated meat products present excellent possibilities for use of minced fish from the by-catch. Researchers in Japan, the United States, Mexico, Chile, and elsewhere have carried out work on combined meat–fish products, but commercial developments have been limited to date.

Mincing has been held as a panacea for use of the shrimp by-catch because the fish present in the by-catch are usually small and because there is a wide assortment of minced products. However, high-quality minced products require prime raw materials, the production of which is not possible with the practices currently used in shrimp operations. Also, in most international markets, the price for minced by-catch would be determined by the availability of larger competitive fish, such as Alaskan pollack. The current price of U.S. $0.15–$0.22/kg for these competitive species may be difficult to obtain for the small, bony by-catch.

Utilization of by-catch as fish meal or silage is also a possibility, although the relatively low price of raw material (of U.S. $0.02–$0.06/kg) limits the interest in this option. As part of an integrated operation for shoreside or factory-vessel processing, the production of fish meal may be desirable but not as a sole outlet for the by-catch. The same principles apply to silage, although it does have an advantage in that the equipment can be operated at relatively low cost on a large scale. Much depends on market demand. For instance, hydrolysates or fish-protein concentrates for human consumption represent a possibility for by-catch use, but the market for these products is limited at present. Access to markets, for example through government clearances, is also very important. Although an immediate market for by-catch in the United States is as raw material for use in pet foods, the restrictions on imports may limit access to it. This market is likely to increase in the future and is already attractive at U.S. $0.09–$0.11/kg.

The technical aspects of utilizing the by-catch are well known, but the economics have not been fully investigated. There is no doubt about the economic attractiveness of landing prime market species, which can command U.S. $0.84–$1.10/kg. The smaller species may also be economically valuable. Nichols et al. (1975) of Texas A & M University showed that, for 10 t of by-catch stored at an ice/fish ratio of 2 : 1 and sold at $0.11/kg, about 50% of the value received would be required to recover the cost of the ice. At $0.22/kg, only 25% of the value would be required to cover the cost of the ice.

Existing Commercial Developments

Mexico, Guyana, Colombia, and the United States have made some inroads into the use of shrimp by-catch, as have some other countries.

Mexico

Mexico has a fleet of some 3000 shrimp trawlers and has plans to replace about 10% of these. The vessels are equipped with facilities to preserve the fish; those with freezing facilities can stay out for 1–2 months, whereas those with ice or refrigerated holds can stay out for up to 2 weeks.

The Mexicans report large incidental catches of finfish along with their shrimp catch — 5–10 t for every tonne of shrimp. Mexico's shrimp by-catch could reach 7×10^5 t annually, an amount equal to about half of Mexico's fisheries catch in 1980.

The fisheries department of the Mexican government has been encouraging shrimp operations to retain more of their by-catch, and a national program has been started to begin utilizing the by-catch in the people's diet. Productos Pesqueros Mexicanos (PPM) has a pilot plant at Xochimilco that produces a new minced fish product called Pepepez. The product sells for about $2.90/kg in shops in Mexico City.

The large species from the by-catch are being delivered to PPM fish-processing and handling plants located at the major ports in the Guaymas and Campeche areas. The small fish — most of the by-catch — are usually thrown away at sea. The fish being utilized are handled in one of three ways — frozen at sea and unloaded at processing plants on shore, packed in ice and delivered to shoreside plants, or brought in fresh for use in fish meal.

Considerable research has been carried out in Mexico on utilization of the shrimp by-catch and on new products. The Tropical Products Institute (TPI, London) has had a project under way on utilization of the shrimp by-catch in Mexico since 1977. Attention has been given to evaluation of the resource, handling at sea, product development, and marketing and economic aspects. Product development has focused on deboned, dried, salted mince for local consumption, and plans have been made for an industrial operation to process the by-catch for human consumption with additional processing of wastes as silage for animal feed. A number of new products are being explored, including canned, minced fish spreads, minced fish cakes, fish–meat sausages, and fish–corn–soybean snacks.

The costs and benefits are difficult to estimate because of the large role of the government in encouraging use of this resource for the national diet. However, even at relatively low prices for the by-catch, there seems to be an economic incentive for the domestic shrimp operations. A shrimp boat landing 10 t of shrimp annually will probably be capable of landing 50–100 t of by-catch. At a price of \$5.50/kg, the shrimp would gross \$55 000, and the by-catch, at \$0.11–\$0.22/kg, would represent a value of \$11 000–\$22 000 or 20–40% of the total value of the catch. Net return would vary with costs of ice, fuel, gear, and the characteristics of the fishery. The Mexican government is considering price incentives and expanded processing installations as means of increasing by-catch use.

Guyana

Information regarding the shrimp by-catch yield and composition off the Guyana coast has been discussed by Allsopp (1980) of the International Development Research Centre (IDRC). Results of a limited number of investigations show a wide variability in the shrimp by-catch, with ratios of shrimp/by-catch as high as 1 : 2.5 and as low as 1 : 30 and averaging 1 : 19.5. Production of 3.3×10^3 t of shrimp in 1978 was estimated to be accompanied by about 6.4×10^4 t of by-catch.

The fisheries of Guyana are somewhat unique in that, within the large quantities of fish recovered in the trawls as by-catch, the marketable portion is high, varying from 24% to 69% of the total by-catch off the Guianas.

A pilot operation is under way at Georgetown, Guyana, in which the large fish in the by-catch are being used as fresh and frozen fillets or whole, dressed fish. Some of the fish are also being salted and dried, and new products that have been processed in flesh-and-bone separators are being introduced. Work is being carried out on use of fish in fish sausage, fish burgers, fish cakes, and a range of minced, salted products.

Colombia

In Colombia, the shrimp by-catch is being processed into human food at the Vikingos Plant in Cartagena. The fish are frozen (whole) at sea and stored in the hold of the vessel with the shrimp. They arrive on shore in good condition at the processing plant and are classified by size. The large fish are headed, gutted, and prepared as frozen round fish or fillets. The small fish are used exclusively as raw material for frozen mince. They are sliced in two, and there is no special selection of species. The waste is used in fish meal. The minced product is frozen in large blocks for use in industry and in 0.5-kg blocks for distribution to supermarkets. Work is being carried out on development of new products from the minced fish.

United States

Some 6000 shrimp vessels operate from U.S. ports in the Gulf of Mexico. The amount of by-catch that could be landed by U.S. vessels is 1×10^6 t annually — an amount that is equal to one-third of the total U.S. production of fish and shellfish. But, at present, there are no programs under way for commercial use of the shrimp by-catch in the United States.[1] Research is being carried out by the National Marine Fisheries Service on using minced fish in fish–meat combinations. Such innovative work is important in any effort to develop new markets.

A number of studies have been carried out on fish-protein concentrates, and some of the facilities to produce them are equipped to handle by-catch and are operating along the Gulf of Mexico. Texas A & M University researchers have explored a number of economic and technological possibilities for use of the shrimp by-catch in U.S. markets.

[1]*Editors' note:* Subsequent information indicates that collection and processing of by-catch are carried out by Deep-Sea Foods (Bayou Batre, Alabama), and the minced product is commercially distributed.

They looked at production of fish meal on the vessels, preservation of the catch, and use of a large vessel to handle the incidental catch.

They concluded that the limitations of facilities and institutions capable of handling shrimp by-catch present a serious problem. The potential profit from handling the by-catch does not seem to be sufficient to encourage adoption of a broad-based utilization system. Also, U.S. regulations prohibit mixing of different species in food products. Steps in the United States seem to be aimed at diversifying shrimp vessels so that they can handle the by-catch and refining the gears to separate the shrimp from the fish. The theory is to develop a groundfish industry in its own right by regulations on the size of the mesh.

Major Issues

The structure, logistics, and limitations of the shrimp fishery and the industry are major constraints to the utilization of the shrimp by-catch. In the United States and Mexico, for example, the facilities for groundfish processing are limited in the ports and areas where shrimp are being landed. The shrimp industry, which is structured to handle an expensive product, has been unwilling to broaden its scope of operations to encompass the handling and processing of by-catch. Industry personnel suggest that processing by-catch requires its own mix of system ingredients and that it should be tied into a groundfish operation that can process fillets, minced fish, and the waste products. Because of the limited shrimping season, trawling for groundfish at other times of the year may be considered. The structure of the industry also suggests that a collector–processing vessel, which can collect by-catch daily from shrimp boats, is desirable. Such a vessel could be equipped to perform freezing, mincing, and disposal of waste in fish-silage or fish-meal plants.

The social and economic constraints derive mainly from the structure and nature of the shrimp industry. The philosophy that one should care for and bring in by-catch, which represents only a fraction of the per-unit cost of shrimp, requires a complete shift in thinking among shrimp producers. The "shrimp mentality" has blocked the path of diversification and is so pervasive that some principal ports and plants, where the shrimp boats unload, will not handle the by-catch.

The economics of the technological options for processing the by-catch need to be evaluated in different locales, with particular attention being given to the prevalent species and the fishery system in the area. In this context, demonstration programs may be needed, and these should include preservation of shrimp by-catch on the shrimp vessel, the use of processing–collector vessels, and production of processed fish items. Two major impediments to evaluation and use of available technology are lack of technical information on the storage qualities and processing of certain tropical species and lack of skilled personnel. The latter impediment means that techniques must be kept as simple as possible.

The by-catch usually comprises a mixture of large fish for which the market demand is high; small, white-fleshed fish; and small dark-fleshed bony species for which there is little or no market demand. The first group may constitute only 5–10% of the by-catch, but it represents the bread and butter of the by-catch operation. The second group has limited market acceptance and includes croakers, small flounders, etc. It is found in local markets in fresh, frozen, dried, or minced forms. The last group unfortunately represents a significant part of the by-catch, although the proportion varies greatly among the fishing areas. This group poses the greatest challenge to product innovators. Minced products to satisfy local tastes in dried, salted, frozen, or canned forms are a distinct possibility.

The basic problem is to create a demand for minced fish from the last two groups. Most of the work in this area to date has been centred on making minced fish an attractive item rather than on incorporating it in meat–fish or snack items. Much of the work appears to be aimed at developing and promoting products instead of analyzing what consumers require through extensive market surveys. In countries where the governments are promoting the use of domestic fish in their population's diet, government authorities are sometimes willing to introduce fish food products into institutions or retail establishments.

The Committee on Fish and Fishery Products of the Codex Alimentarius Commission is developing international standards to allow for the use of different species in minced-fish blocks; the aim is to encourage countries to revise unnecessary rules and regulations that hinder the use of by-catch and restrict trade.

Some concern has been expressed about the presence of toxic fish in the by-catch in tropical areas and the possible introduction of marine toxins into food destined for human consumption. There are some species, such as bullseye puffer, that contain a potent neurotoxin. These fish are easily recognizable, however, and can be easily separated from the catch. There have been no official reports of adverse effects to people consuming by-catch products, but, as the by-catch becomes more commercially important, it will be necessary to take safeguards that ensure the removal of toxic fish.

A comprehensive approach toward removing the impediments to by-catch use would involve analyses and introduction of regulations and suitable price incentives.

The Food and Agriculture Organization expresses its great appreciation to fisheries authorities and many fishery experts from government and industry for the time and effort that they spent in responding to questionnaires, in providing special analyses, and in speaking with me. Without their assistance, kind cooperation, and advice, this paper would not have been possible.

Use of Fish By-Catch from Shrimp Trawling: Future Development

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Much investigation and industrial development in fish by-catch use has taken place since my review (1980) presented to the Inter-American Development Bank (IDB) Round Table on Non-Traditional Fishery Products. However, there are critical areas for further study to resolve technical and economic constraints in each system. In this paper, I have indicated these as well as some locations where relevant developments are being investigated. Specific subjects for international action are identified in the fields of gear, vessel modification, product development, and resource management.

At present, the by-catch of shrimp trawling is usually discarded — a waste that has serious implications for food consumption in tropical countries where many fisheries are already shrinking in production. Further, because the total marine catch is some 6.3×10^7 t, of which 4.3×10^7 t is consumed, the use of the by-catches could enlarge fish supplies to protein-deficient areas in a major way.

Fish Available

Because of the variations in the seasons, ocean floor, water currents, time of day of fishing, migratory patterns of groundfish, etc., it is impossible to arrive at a fixed ratio of fish to shrimp even in a particular area of a fishery. Catches vary considerably, especially where seasonal currents or estuarine outflows cause temperature changes or where the associated fauna are diverse. Thus, fish by-catch in Mexico's north Pacific coast (Baja California) is much different from off Tehuantepec, and it is completely different from the Yucatan, Colombian, or Guyana species combinations on the Atlantic coasts. Although it is an oversimplification to give a ratio of 5 : 1 by-catch/shrimp in fisheries in temperate waters and a 10 : 1 ratio for tropical waters, it is a useful guide.

The size of fish caught is also variable. A broad classification according to market demand is:

- Large marketable species;
- Marketable species of medium sizes (15–25 cm) and larger unusual species; and
- Small fish of marketable characteristics (white flesh, few bones, etc.) or unusual species less than 14 cm.

This classification can be subdivided into quantities by species groups. If one accepts these categories and recognizes that, in each country, fish that are marketable vary considerably, it will be appreciated that what is available for human consumption varies even further and that total by-catch estimates of discards or marketable species for any given fishery are rather subjective.

The FAO figures for by-catch discards have changed over the years from 3×10^6 t to 6×10^6 t. A National Academy of Sciences (NAS 1978) study encompassed a range of what may be edible and what may be used only for industrial purposes. The U.S. Gulf of Mexico fisheries have recently indicated a figure of about 1×10^6 t for their vessel discards.

Clearly, there is an enormous cumulative waste through discards, and, although much time may be spent on arguing its accurate estimation, efforts to quantify the by-catch in different areas would be more profitable. Preliminary work has been started in the Guyana/IDRC project. The U.S. National Marine Fisheries Service (NMFS) has analyzed data based on statistical samples and has extrapolated the results to the vessels operating in the Guyanese fishery. Donald Furnell, in a report to IDRC, indicated that an average 2×10^4 t fish were caught as by-catch during each of July and August by the Guyana fleet. This figure may be typical for the rainy season only, and data have to be collected from several boats during different seasons and in different locales. The patterns of availability and capture of fish/shrimp in different zones in other countries and for the duration of the seasons are important baseline data. Such assessments form the basis for further industrial action.

To be meaningful, the quantities of fish should be grouped according to their flesh characteristics for industrial end-use. The result of the removal of fish stocks and the management implications of this fishery are relevant issues that must also be faced.

Recovery, Handling, and Preservation

Whenever there is a large quantity of fish caught during shrimp trawling, the crew must devote considerable time and effort to sorting and separation. This fact has led to the design of separators, excluders, and escapement chutes in trawls. The objective has been to land a clean catch of shrimp. Most of these designs have been developed for fisheries of northern and temperate waters where the quantities of fish and the behaviour of the shrimp are somewhat different from those in tropical waters. The bibliography in this publication lists many of these. My understanding, from personal communication with the authors is that, with further studies and modifications, the principle of presorting can be perfected and applied to tropical penaeid fisheries. Such a development would facilitate the sorting of shrimp and fish, reduce handling time, and permit better preservation. It would require skilled net rigging and use. Further applied research on other gear improvements is important if catch efficiency and handling are to be improved. The different systems for separation, as well as the wide-opening, catchall trawls developed by Deep-Sea Boatbuilders of Bayou la Batre, Alabama, should be assessed and standardized. The proposal for a study to test the use of sound to direct the fish away from the trawl is also promising for joint-venture enterprises fishing in the exclusive economic zones (EEZs) of tropical countries.

Part of the reason that the by-catch is discarded is the limited space aboard the shrimp trawler. One way to alleviate the space limitation is to sort the fish mechanically as the cod end of the trawl is discharged. Other technical options involve stowage systems that include facilities for freezing, CSW storage, or mechanical systems of handling in bulk. The cost–efficiency of these options, however, has yet to be evaluated. There have already been new designs introduced for boats in Mexico and in the USA (Bayou la Batre, Alabama) with greater space for storage and crew members. The results of their operations in the fisheries should be carefully assessed. However, because of climatic conditions, fish abundance, and cultural customs, the designs may not be totally transferable to more tropical areas.

Specific additional needs include:

- Improvements in harvesting gear on the vessels;
- A simple mechanical device for separating, grading, and sorting the fish by sizes aboard the vessels (after being graded the fish can be sorted into species groups more easily and stored as such; in this regard, the Danish experience is relevant);
- Study of the stowage space required for shrimp and fish (according to the operational locality of the vessel) as a basis for redesign of vessels for specific fisheries; and
- Techniques and equipment for efficient handling aboard and for port discharge.

The use of small trawlers that make short trips (no longer than 5 days) combined with arrangements for using trawlers for fish only is being attempted in some countries. The alternative — use of much larger trawlers to bring in all the catch — is operational in Alabama and Mexico and is planned for Guyana. Management studies of boat-size limitations and operational zones for particular vessels and gear may be needed as well as specific evaluations for the implementation of efficient operations.

Vessel owners have tended to replace old vessels with larger trawlers with freezing facilities, but their target has continued to be shrimp. Government enterprises (Mexico, Guyana) have begun building larger boats with CSW systems for fish and shrimp. To date, I have no knowledge of collecting systems that are in regular commercial use.

Purse seiners equipped with CSW systems are available in Mexico and may be available in off-seasons for tests of the transfer and collection at sea of fish by-catch from shrimp trawlers. The system suggested for the Guyana fleet was the use of tanks (fish-holding capacity 2 t) on deck for nightly transfer to collection vessels. In both cases, the operational patterns of collector vessels, rendezvous with trawlers, transfer of catch at sea, the quantities of fish in particular seasons, and other variants need to be carefully analyzed.

Incorporating, in the design of larger vessels, the use of mechanical graders for the selection of species and categories, as well as possible processing (deboning) at sea, seems to be a suitable approach. If adopted, this approach would mean that transfers of catch would involve only the large species that can be sold whole at premium prices. Selected smaller species could be minced and frozen or salted for storage. Transfers would be minimized, and the bulk of fish would be reduced in the form of frozen mince, stored similarly to shrimp.

A fleet of CSW-equipped vessels is only part of the production system; another element is shore installations and plant processing to handle the catch efficiently. In a hot climate, cost–efficiency of the system is critical because refrigeration is involved. In this regard, the system of minced, salted fish developed in Canada (Halifax), if done and discharged in ports, is promising. Further, the market value of the fish and the end-use may dictate that the recovered by-catch be limited to the space available on the vessel and that, as a last resort, fish be landed for conversion as livestock feeds. The champagne-bubbling system of chilled seawater for handling, storage, and port discharge used in the Pacific northwest and in Denmark is worthy of trial on an industrial scale. The results of testing this system in Guyana and in Bangladesh should be followed closely. In an integrated system from capture to processed product, the essential stages requiring improvement have to be considered concurrently. The volume collected, the scale of pilot operations, the quantity of inputs for commercial-scale operations are all related to the products for target markets and for which a set of criteria of characteristics must be predetermined (Fig. 1).

Processing the By-Catch Ashore

There are between 70 and 200 species involved in the tropical by-catch. They vary greatly in shape and size and, even after being sorted and graded, are unsuited to the mechanical processing methods currently available. Large fish can be manually headed, gutted, etc., but small fish (which constitute as much as 50% of the catch) require machine heading, gutting, or filleting for desirable quality and low costs. Most processing equipment (manufactured in Europe, North America, or Japan) requires modification to cope with the types of fish that are most abundant in the by-catch.

The different species of fish in the "white-flesh" category may have to be subdivided according to flesh colour, texture, elasticity or toughness after cooking, and their suitability when mixed with cereals or starchy food additives. There is considerable variation among species and among the same species during different seasons. Accordingly, tests related to the end-use of different species should be done. Specifically, the texture, toughness, etc. of minced fish after being frozen or cooked have been found to be quite variable. Mixes of different fish flesh may thus result in textures of end-products that are not uniform. Further, mixes that include fatty fish may undergo rapid denaturant reactions even when frozen.

Tests for product development, therefore, must involve careful study, preferably in well-equipped, food-processing laboratories, of the flesh characteristics of the prime species available. The results can contribute to product formulation suited to various national and cultural tastes.

Logical steps in promoting the development of food processing move from pilot-plant operation through commercial production to consumer product development, testing, and evaluation. Storage, shelf-life, packaging, standards, grades, and promotional methods are involved. On a local or national scale, these are formidable tasks. The international or regional scale should only be considered when domestic markets are satisfied and the profitability of operations is established. The requirements of international markets involve considerable financial inputs for promotion of new products and assured volume. Joint-venture enterprises may facilitate such activities after the local operations have had experience in effectively handling the available by-catch resource.

The large, marketable species can be sold in traditional forms, which include fresh or frozen fillets, steaks or dressed fish, and preserved products. Increasingly, however, it has become evident that whole, dressed fish or frozen fish are less commercially profitable in tropical countries than are various stable products. The reasons are the low purchasing

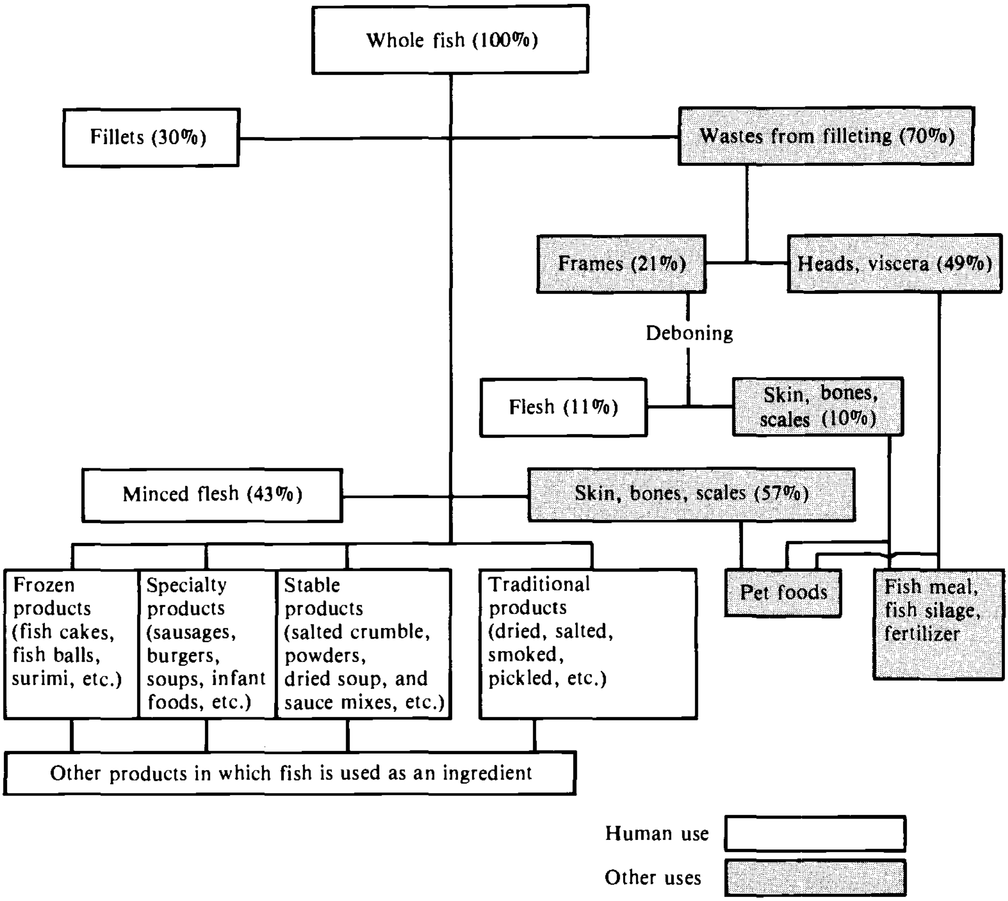

Fig. 1. *Approximate recoveries in processing of by-catch fish.*

power of the populations, the importance of fish as a source of protein, demand for fish, and the increasing costs of refrigeration, electricity, and fuels. Although frozen storage may be accessible to high-income urban dwellers in the tropics, it is too costly for others, especially rural consumers. Thus, products that require minimum energy inputs and are stable at ambient temperatures are desirable. These include salted, sun-dried, and pickled products. The methods for making pickled and smoked or barbecued products are already in use but need improvement and standardization. To provide products that are acceptable, bulk-produced, effectively packaged, with adequate shelf-life, requires further developments and studies with selected species. This is the area of greatest challenge for researchers: to develop bulk processing of dried, salted, or pickled fish on a scale of at least 10 t/day as well as on a village scale of 2 t/day. Standard quality and effective packaging require special attention.

Nontraditional products offer a wide range of possibilities and have been the subject of many developments using deboning machines. In Mexico, Colombia, the U.S. (Alabama), Guyana, Nigeria, India, and Malaysia (Sabah), various products are being made by this method. For instance, minced croaker seems acceptable for the Japanese surimi market. Various flesh-and-bone separators are available, but few are really ideal to cope with the variety within the by-catch. What is needed is a machine that can:

- Process a wide range of sizes of fish;
- Recover a maximum amount of flesh without bones;
- Be cleaned easily, with few wearing parts in need of replacement;

- Be constructed from long-lasting materials; and
- Handle large throughput for economical plant operation.

Some consider that a small plant (2 t/day) may be effectively used on a trawler; others urge a large deboner (20 t/day) for onshore installations. In any event, there is a need for modification of current machinery to deal efficiently with the fish available in the by-catch.

Once minced, the fish flesh is versatile (Fig. 1). Not only is mincing an efficient way to recover flesh for direct use as human food, but also a wide range of by-products, such as pet foods and livestock meal, can be made from the bones as well as the scales, liver, swim bladders, etc. Such products have already been developed in advanced technical laboratories and commercial plants using fish from trawl fisheries of temperate waters. Studies on flesh characteristics to test the suitability of the different fish types for various products in local markets are necessary. In addition, shrimp heads offer opportunities for valuable products.

The aim should be to produce new types of "convenience products" that are stable at room temperatures; have a shelf-life of 1 year; are packaged against insect attack, moisture loss, and denaturing; are suitable for quick domestic or institutional use; and require a limited amount of preparation before being brought to the table.

Snack products, such as fish crackers, biscuits, etc., developed according to local tastes with spices, peppers, etc., are already made from minced fish. Their inclusion in Mexican tacos, tortillas, Indian rhotis, and Indonesian krupuk or fish fritters has already been done. In addition, burgers, pastes, sausages, wafers, rolls, and puffs, in which fish are used as an ingredient, are available. Such products will cater to middle-income earners, institutions, and urban communities. There is clearly a market for them, and it is increasing in most tropical countries.

Oily species that are part of the by-catch have been considered suitable for use in fish meal and cooking oil. Some of the smaller species of mackerel are pickled, the larger ones being directly consumed. A smoked fish pâté, using cavalle, is a new product that found ready market acceptance in Guyana.

Livestock feeds logically form part of the recovery systems for by-catch fish. The smallest fish caught in the trawl, rather than being discarded, can be used for fish meal if they can be economically brought to the shore plant. Simple systems of fish-meal processing at small fish-silage plants have been advocated within the past 20 years. Frames from filleting as well as processing wastes from flesh-and-bone separators can also be used in fish meal and fertilizers.

Therefore, the economical processing of by-catch seems to depend on the combination of approaches to the use of the fish available to meet consumer tastes in the local or regional markets. It would include:

- Use of large species for direct consumption in various forms;
- Manufacture of traditional products;
- Manufacture of minced fish and specialty products;
- Manufacture of pet foods;
- Recovery of wastes as livestock feeds; and
- Use of shrimp heads in chitosan and other products.

Because local-market price levels are already fixed for most of the classes of products, the opportunity for greatest development and cost recovery lies with the development of nontraditional minced products. This development would upgrade the value of the flesh of the most abundantly available, low-priced species and could present fish protein to the consumer in a highly acceptable form.

The assessment of the combination of end-products, the most profitable species of fish for minced flesh use, the quantities of product types for markets, etc. is critically important if one is to determine the most feasible commercial operation in particular situations. Such considerations are clearly affected by local circumstances of market demand, as well as international factors like fuel prices and costs of vessels and gear, even though the overriding principles of import substitution and protein self-sufficiency apply in some cases.

Processing questions may, therefore, be summarized as:

- How do the flesh characteristics of principal species of the fishery affect minced products, and how is the texture affected by different combinations of processing steps (such as mincing, freezing, and then converting into mixed products compared with freezing, thawing, mincing, and converting)?
- What are the best uses for the abundant

species in the by-catch as a reflection of studies on the products best suited for distribution, the products most profitable in processing, the target market (institutions, rural residents, urban dwellers); the economic mix of products needed to make a commercially viable operation; the price that the market can bear; the maximum price to the producers?
- What other technical and economic decisions need to be taken for use of different species for various products?
- How do taste panels react to the products developed?
- What are the characteristics of the products, i.e., what is their shelf-life; can they be produced in bulk for institutional use?
- And what are the characteristics of the postproduction system, i.e., does it include items that have fish as an added ingredient (soups, bread, tortillas, biscuits); low-cost, fortified traditional foods; specialty products (high value) including chitosan from shrimp heads; and animal feed?

After products have been made successfully on a pilot scale, testing of large-scale production should begin and should include cost analyses. In areas where market demand for fish outweighs supplies, test-marketing of by-catch products can be undertaken mainly on the basis of taste-panel testing. In some cases, governments or donor agencies may subsidize efforts to popularize products and get them to the target populations. An interesting regional market survey has been made for six Caribbean territories with the products from Guyana. Yet, to date, the costs and benefits of using different species in products have not been evaluated systematically in relation to the target market — what the consumers want or require most and what price they can afford.

Market studies need to reach both rural and urban consumers as well as those who buy food for institutional programs. The variations in products for specific locales (storage, shelf-life, transport, etc.) are important factors to be considered in local as well as regional surveys. Another important factor is quality. Although domestic markets may permit products of variable standards, international or regional markets require adherence to fixed international standards of the Codex Alimentarius.

The major outlet for minced fish products prepared as convenience foods is institutional food kitchens, i.e., schools, hospitals, etc. School-lunch programs, office canteens and cafeterias, quick-food outlets, food services in health-care centres or confinement institutions are excellent opportunities for the bulk sale of well-compounded fish preparations. Standard quality, hygienic excellence, and attractive taste are essential in such markets; a dependence on the nutritional value of products is clearly not enough.

One method to reach the institutional market is to prepare minced flesh in bulk, provide it to food-processing outlets, and then move the products to the target institutions. Bulk preparation could include dried, salted fish "crumble," dried soup mixes, fish sauces, etc. at standard mixes distributed for institutional use or packaged for sale to individuals.

In tropical countries, the outlets that would be processing fish for human consumption should be separated from the fish-landing areas where preliminary handling and processing take place. In contrast, the manufacture of livestock feed from industrial fish, fish offal, trimmings, and the wastes from the deboning machine should be close to preliminary-processing operations.

Economic Aspects

The critical reasons that by-catch fish have been discarded are market value in relation to shrimp and stowage space aboard a trawler. If the value of the fish were increased through processing activities, the shrimpers might be convinced of the benefits of collecting the by-catch, especially if the cost–benefit compared well with that for shrimping. A cost–benefit comparison needs to be based on:
- An operational cost analysis for shrimp fishing with different boat types (equipped with freezers, ice, CSW), including fuel, maintenance, machinery depreciation, and catch returns in specific fisheries;
- An economic study of the opportunity costs in the use of stowage hold for shrimp and fish during trips in different operational areas (most shrimp trawlers return with half-empty holds that could have been carrying fish without damage to the quality of stored shrimp, according to evidence from Mexican operations that offer a variety of conditions for study in

standardizing the system of stowing by-catch and shrimp);

- A study of the patterns of capture (volume of fish/shrimp) and an assessment of the value of residual space at the end of shrimping trips; this information could be used as a basis for timetables for stowage use of the hold; and
- A realistic cost structure for different categories of by-catch that would serve as an incentive to owners and crews to collect fish of good quality for food processing (not livestock meal).

Products that increased the market value of by-catch not only would result in enlarged sea operations but also would have a multiplier effect on employment, generated by shore-based activity for food products, livestock feeds, etc. Another social factor, although difficult to evaluate in economic terms, is especially important: food self-sufficiency and the use of nationally available resources. Further, processing the by-catch for human food would provide an insulation against spiraling prices of imported foods.

Regulatory, Legal, and Monitoring Aspects

At present, data on catches are scanty; there have been few surveys of the by-catch fish during commercial shrimp trawling. However, some surveys have indicated the catch of shrimp or of fish; for instance, U.S. survey data for fishing in the north of the Gulf of Mexico and off the Guyana banks are being analyzed. In other areas, specific data may be extracted from shrimp-fishing records in logs of operations — for example, from Japanese-owned trawlers — and from operational catch data reported daily — for example, for trawlers fishing along the Atlantic coast of Colombia for Vikingos. Other data are available for Sabah, Malaysia, and Andhra Pradesh, India, as well as for areas off Bangladesh.

Constraints on data collection include the limited space available even for crews on trawlers, the limited numbers of personnel skilled in navigational reporting, and the limited interest in fish (quantity by species). Because of the variations of catch in different locales and seasons, the data available are generally not suitable as a basis for industrial applications and are even less suitable for regulatory or management measures for fish or shrimp. The navigational fix of the trawling area, the water currents, sea floor, temperature, etc. have been recorded only in surveys done by research vessels. Furnell in a report to IDRC suggests a simple sampling system for catch data. The actual catch of shrimp is generally well recorded, but the location of capture is generally vague and even secret.

By-catch data must be recorded by vessels and must be accumulated for assessments about management and monitoring. Data assessment systems should be standardized, captains trained, and logs or records required. In some countries, e.g., Colombia, each vessel must report daily its location (for security control), and this information can facilitate shore-based monitoring of catches. In certain fishing operations, national data collectors are reported to be aboard foreign vessels to record catches from their countries' exclusive national fishing zones.

The EEZs were set up as a means to introduce better management of the resources within the waters along the coastal areas of the world. One possible management strategy is to restrict fishing in waters up to 15–20 fathoms to national artisanal fishing enterprises; to allow offshore (perhaps within 20–45 fathoms) trawling for shrimp and fish seasonally or by limited numbers of vessels; and to consider the remainder (40–100 fathoms) of the area within the EEZ the domain of foreign vessels with specialized gear such as separator trawls, etc. (Fig. 2).

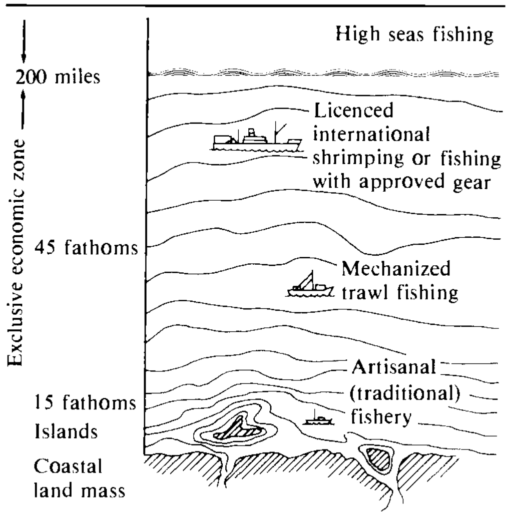

Fig. 2. *Possible zones for shrimp fishing.*

A complete management strategy, however, must include regulations on mesh size and other gear. The FAO regional fisheries commissions must take the lead in providing the technical basis for regulatory measures and their cooperative application by all countries fishing the resources. Some centres already have experience in such data analysis, and they should be identified and their collaboration enlisted. In this regard, the industrialized fishing nations, particularly Europe, North America, and Asia, can provide useful leadership and training opportunities in specific aspects of resource studies, management measures, and product-development standards. The centres that are involved in data analysis from overseas shrimp fisheries have a special opportunity and responsibility for the national use of by-catch fish.

Quality control of exported products made from the by-catch is governed by international regulations. Standards for national products are equally important, for they ensure that high-quality food products are available for human consumption and they present an opportunity to eliminate the slur and uneasy image of by-catch in the past — trash fish to be thrown away or used only in animal feed. Therefore, enforcing hygienic and quality standards is essential, particularly because the fish species now have low consumer demand. Lapses in quality of marketed products will seriously damage consumer-promotion strategies.

Special Regional Developments

The geographic area where activity for by-catch use is primarily evident is the Gulf of Mexico and Latin America. However, in West Africa, the Indian Ocean, South China Sea, and the Indonesian seas, various activities have been initiated. Although there are many traditional fish sauces and minced products in use in the Indo-Pacific area, particular emphasis has recently been given to fish silage and community processing because of massive quantities of small fish in the by-catch from the Gulf of Thailand, Bay of Bengal, etc.

Challenging opportunities for technological research and development in capture and processing include:

- Improved design of trawlers to catch and separate (or exclude) the fish from the shrimp;
- Redesigned vessels to accommodate the total catch safely and economically;
- Mechanical fish sorters and graders for on-board operation;
- Efficient storage, collection, and transfer systems in vessels;
- Processing techniques that accommodate different flesh characteristics and product development;
- Modifications of filleting and processing machinery so that it can cope with the bulk of the by-catch species harvested; and
- Management systems for sustaining resource yields.

Already, in governmental or industrial laboratories, skilled personnel address these challenges. However, they are finding solutions and designing systems to fulfill the requisite need for their specific fishery. What seems to be needed is the acceptance of the prime importance of these challenges in contributing toward food benefits and toward an integrated multiplier effect. Clearly, if enough effort were devoted to the meeting of these challenges, results would be attained within a few years. A concerted effort at training and the effective application of the principles, with systems tailored to the different geographic and national locations, is needed so that the recovery of the by-catch fish increases dramatically.

Investment banks should consider devoting funds toward solving some of the specific problems in by-catch use as well as toward developing the needed production methods and infrastructure. I believe that concerted international efforts can reap the rewards of by-catch use and that the rational management of such resources under the new regime of the oceans will make the greatest possible contribution to the resolution of the planetary food shortage.

This paper summarizes my observations of fishery operations in the production and processing of fish by-catch in several countries during 1980–81. The observations and discussions with personnel in the USA, Denmark, England, Mexico, Colombia, and Guyana reflect activities and constraints at the production and processing centres. I very much appreciate the frank discussions with such technical personnel and the opportunity to observe many processing operations, gear modifications, and new vessels. Also I have drawn on correspondence and literature sent to me by fishery personnel.

By-Catch for Human Consumption

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I intend to identify the major problems that, in my opinion, require solution and to focus on possible approaches to solving these problems, indicating solutions that have been successfully tested or that have been suggested for implementation. I will concentrate my remarks primarily upon suggestions that can be implemented on board the existing shrimping vessels. I believe the present problem — the waste in shrimp by-catch — far transcends in importance the needs of the shrimping industry. It needs a systems approach for its rational approach and resolution.

The urgency of the economic, energy, and food situation, worldwide, makes it imperative to devise means to reduce food loss and willful waste in both developing and fully industrialized countries. According to the U.S. Comptroller General, 20% of all the food grown in my country is lost. The reasons for waste are many, often firmly based upon long-standing systems of custom and belief, and it is usually easier to increase food production than to reduce waste.

Identification of Problems

The question is how to use, more efficiently and economically for human consumption, one of the by-products of the shrimp fishery, the by-catch, which constitutes a variable multiple in weight of the major harvest — the shrimp itself. If one is to consider the utilization of as great a proportion as possible of the by-catch for human food, it becomes necessary to look at the whole sequence of activities from harvest to consumer and address the problems that are being encountered at every step.

Solution of many of the problems is by no means important only today but will, in my view, become much more crucial in the future, when near-shore shrimp stocks will have dwindled, the shrimp will have moved farther away, and an even greater energy input will be required in harvest; energy prices are most likely to have become even more exorbitant, and the resource now called by-catch will have become the major — perhaps the sole — harvest required to feed hungry mouths everywhere. I predict, therefore, that the shrimp catch, a profitable luxury in industrialized countries today, will become scarcer — and perhaps generally unaffordable — and that the problem of efficiently utilizing the mixed-species by-catch will become the most important concern of fishing fleets here and elsewhere.

What, then, is the sequence of activities that we as experts in the field have to look at, the attending problems encountered at different stages, and the solutions or suggested strategies for developing appropriate answers to these problems?

It appears universally accepted that, because of the overall lifestyle of the shrimp, the method by which this resource is harvested today leads to the landing of hauls that consist of a large and variable composition of animal species within which shrimps represent only a relatively small, albeit most valuable, part. The shrimp, therefore, have to be separated from the rest of the catch by labour-intensive means on board, the by-catch — itself comprising many species — being tossed overboard.

The questions, here, are: Can shrimp and nonshrimp components be separated less expensively, more efficiently than is done now, and perhaps automatically, in the water or on board? Can separation be extended to the sorting of the fish species in the by-catch?

The valuable shrimp catch is preserved (frozen or packed in ice) on board, and preservation would also be necessary for the non-shrimp component if it were to be used for human consumption.

The questions, here, are: What methods are available today that will, at the smallest expense, make it possible to preserve the by-catch for the longest possible time, either gutted or ungutted? What is known about the storage conditions appropriate to preserve the different by-catch species?

In processing of the by-catch, the questions are: Whereas the frozen shrimp may be landed heads-on or heads-off, what processing steps for the by-catch can be performed efficiently and economically on board the shrimping vessel before the by-catch is further preserved and landed? What methods are available for processing the fish on land to enhance the by-catch value significantly? In particular, and most importantly, what are the techniques that are available for processing the usually large proportions of small fish present in the by-catch?

The shrimp harvest commands a known market price and represents almost hard currency by itself. Consisting of an unknown mixture of species of various sizes, the by-catch, in contrast, has an unknown market value.

The question, here, is: What are the economic considerations that must be taken into account if the treatment of the by-catch is to be economically attractive?

The acceptability of shrimp and the marketing strategies for disposing of the shrimp catch are about as unequivocal and clearcut as those of any other single commodity — salmon, glycerol, petroleum, etc. — of international trade. This, however, is by no means the case for the by-catch, as a bag of mixed species or as single species.

Question: What are the acceptability characteristics of the by-catch components in different countries, for different populations, i.e., for different species of fish, differently processed and presented to the consumer as different end-products?

Possible Approaches to Answers

A few approaches have recently been suggested as means to answer some of these questions and may have promise for easy and sometimes inexpensive adaptation to local conditions. To these, I wish to add my own recommendations.

Harvest and sorting of catch

As pointed out by Sternin and Allsopp in this volume, a number of selective fishing methods and gears have been proposed and developed; some have been tested with results that promise to reduce significantly the proportion of by-catch during the shrimping operation. To their excellent discussion, I would add the work done by Seidel and Watson (1978) of the Southeast Fisheries Center in Pascagoula, Mississippi, and published in September 1978. They describe a selective shrimp trawl that uses electricity to induce the shrimp to jump through a large-meshed bottom panel into the trawl and the fish to move ahead of the electric field and avoid capture. The underlying principle is that shrimp and fish react differently to an electric field. Although not widely accepted at present by the fishing industry, the electric shrimp-trawl system should, along with similar developments, be pursued because it is an effective harvesting device that promises to increase shrimp production in day or night operations. The main advantages of such a harvesting strategy would be increased harvest for the effort expended, greater profit, and, therefore, the possibility of subsidized harvesting and processing of the underutilized food fish; these benefits would make food-fish harvesting more attractive to the producer. Although interesting experiments have been conducted recently in Fiji (Brown and King 1979) to harvest shrimp in deep-water traps, the possibility of widespread introduction of this method seems too remote to warrant further discussion here.

As long as selective fishing methods are not widely adopted, one can assume that considerable by-catch will be produced and will have to be handled by the crew of the shrimping vessel. Equipment to sort the catch automatically into shrimp and large, medium, and small fish by pattern recognition can, of course, be assembled but would be very costly in vessel space as well as dollars. I feel, therefore, that, for the time being at least, one has to deal with the question of whether the mixed by-catch, from which the shrimp have been removed manually, should be preserved immediately or presorted on board and then stored. I do not believe that a single approach can be generally applied because the decision will largely depend upon local conditions: on-board storage capacity, availability of suitable shore facilities to process small species, marketing conditions, local regulations concerning permission to process mixed species, etc.

Preservation

Especially in view of the decline of the shrimp catch per unit effort in the Gulf of Mexico (Seidel and Watson 1978) and elsewhere but also in view of increasing costs of fuel, dramatically increasing food needs worldwide, etc., the problems in preserving and utilizing the less-valued food fish such as spot, sand seatrout, black sea bass, juvenile croaker, Gulf menhaden, silver hake, blue whiting, etc. transcend in importance the question of what to do with the conventional shrimp by-catch; what is now referred to as by-catch may very well become the major food fishery of tomorrow, and one must learn how to deal with it.

Recent publications indicate that preservation of single or mixed species of fish in mechanically refrigerated and circulated seawater (RSW), RSW with spray, or chilled seawater (CSW) — a slushy mixture of ice and seawater — is more desirable than preservation of fish in ice. Baker and Hulme (1977) found that fish held in CSW are more readily unloaded by pumps than by the traditional basket method and can be separated more economically on shore than at sea. Sea trials resulted in superior-quality fish, the only questionable disadvantage being the scaling that occurred in rough weather. Although the studies were conducted with the lean fish in the by-catch, fatty fish, also, can be much better and longer preserved in CSW than in ice. The system, tried in Morocco with sardines and reported this year in Boston, is easy and quick, the low temperature of the slush helping to maintain good texture of the fish and the water acting as a buffer to prevent bruising. There is indication that CSW provides protection against rancidity.

Although the technology for RSW and CSW has been used for preserving industrial fish for at least 10 years, application to the food-fish industry has lagged. The National Marine Fisheries Service (NMFS) laboratory in Charleston, South Carolina, has therefore undertaken shipboard tests to compare the economic and qualitative effectiveness of RSW and CSW systems when applied to representative underutilized species from the U.S. southeast, especially croaker (*Micropogon undulatus*) and black sea bass (*Centropristis striata*). Not surprisingly, the results are encouraging.

Another method, worthy of mention because it allows easy and inexpensive application anywhere, concerns the methods that Icelandic fishing personnel, especially shrimpers, use to transport fish for human consumption. In Iceland, the 70–80-L plastic box has completely taken over the deep-sea trawler fleet and the smaller inshore boats. The latter land their catch ungutted and need, therefore, a method for quick and thorough chilling of their haul. Icelandic fishing personnel use the boxes for CSW preservation and have found that the hours of labour needed on board and on land with this method are half those needed for icing of the fish.

Húsavík, in northern Iceland, is one of the fishing villages where most fish are landed by small inshore boats and are ungutted. Mostly, the boats land their catch in the evening — a fact that produces labour problems. Thus a cold-water tank system was purchased from the firm Kvaerner Kulde A/S with a capacity of 40 m^3 or 22–25 t of fish. It has a unit for refrigeration and circulation of fresh or salt water and can use ice for cooling, too. The system can lower the temperature of the tank's contents from about 10°C to 0°C in 4 hours. In Húsavík, fresh water is used for the system, kept at 0°C throughout the keeping period.

Removal of fish from such tanks has been a major problem. For the tank at Húsavík, a compressed air system was developed. Thus, the fish are lifted to the surface by air bubbles. A conveyor then takes the fish to the processing line. Emptying the tank (25 t) only takes 30 minutes.

In the course of a workshop, in January 1981 in Sumatra, examining fish handling to reduce postharvest losses, the use of fish-storage boxes was demonstrated by the ASEAN Food Handling Bureau in Kuala Lumpur, Malaysia. The results obtained in several countries using the containers included improved quality of fish and better revenues for the fishing personnel.

Preserving fish in containers with CSW is also of considerable interest in Denmark where layering techniques were developed to accommodate slow filling of containers with intermittent arrivals of fish. In a paper given recently on this subject by Poul Hansen of the Danish Ministry of Fisheries, results showed that the bacterial counts are always lower in CSW-stored fish than in fish in melting ice. The difference is most pronounced when the chilled seawater is not aerated, in which case ultimate spoilage of the fish is caused by anaerobic organisms. The slush seems to protect against fat oxidation and rancidity in fatty fish better than does the melting ice. However, the use of containers for RSW and CSW preservation depends heavily for its success upon the existence of a reasonable infrastructure to provide transportation, loading, unloading, and other facilities at sea and on shore.

Processing

A vast array of products, processes, and equipment has been developed during the last 10–20 years for underutilized species of edible fish. A good account of some of the most important of these products and processes is available from the Inter-American Development Bank (IDB 1980).

One of the important points not sufficiently discussed in the IDB document is the problems of dealing with very small fish that, often, constitute almost half the weight of the by-catch. Apart from the manufacture of fish meal for human consumption from such fish, undertaken in Norway in sanitary equipment and under carefully controlled conditions, no process or machine is available or even on the drawing boards capable of heading, tailing, gutting, and cleaning small fish (12 cm) on board a fishing vessel. If, in the future, small fish are to be fully utilized as human food — not as raw material for fish meal for animal feed — serious consideration must be given to the question of how to process this type of fish. Processing would probably have to be done on land because the machines that will be used will be sensitive, operate at high speeds, require special maintenance provisions, etc. The technology for this kind of operation certainly exists but is, so far, still much too expensive for installation on board a fishing vessel. A reasonably successful prototype of such a machine for land-based operations was recently built and tested in Gloucester, Massachusetts, by the NMFS, processing small fish (3600 fish/hour or a fish/second). The price tag for this machine was about U.S. $40 000, but the machine needs much improvement, especially in its capacity to handle a range of fish sizes (Mendelsohn and Callan 1980).

Economic considerations

If one assumed, for the sake of my argument, that all the questions concerning harvesting techniques, sorting, preservation, processing, end-product acceptability, marketing, and distribution of the by-catch were solved, what would be the major economic considerations? They are more complex and thornier, by far, than are the purely technical problems.

The first and overriding consideration is the magnitude and nature of the incentive that the shrimper or shrimp-fleet owner needs to be persuaded to reequip a vessel, retrain crew, and make a concerted effort to preserve part of the by-catch. For, as long as shrimp remains the major crop and commands a much higher price than the by-catch species, persuading this individual will be very difficult. Persuasion will, of course, become easier as the abundance of shrimp dwindles and the by-catch becomes more desirable and, thus, more valuable. Initially, subsidizing by-catch recovery and processing may be necessary to introduce the idea to the fishing industry and demonstrate at least its technical feasibility.

There are, however, other avenues that can be pursued to make the economic picture more attractive. For instance, in view of the spiraling fuel costs, my colleagues and I at Massachusetts Institute of Technology (MIT) are working on methods to provide fishing boats with sail assistance to save fossil fuel. Of course, wind power will not always be sufficient to drag the trawls, and different boat structures will require different riggings, but appropriate sails could get the fishing boat to and from the fishing grounds. We expect this fact will represent a very substantial saving over time. Sail-assist technology is advantageous because financial gain is immediately apparent and can be used as a basis for convincing vessel owners.

Another attractive avenue capable of saving money is the use of engine waste and exhaust heat, either for drying fish on board or for the production of ice or other forms of refrigeration. As simple and effective means of preservation are core considerations for any successful by-catch utilization scheme, any process to make refrigeration a less capital-intensive undertaking is important.

Market considerations

I will not spend time on market considerations, but I should emphasize that market conditions are, by definition, highly locale-specific, depending upon national and regional legislation, regulation, cultural preferences, food customs, per-person income, social structure, nature of the available resources, etc. Does the food and drug administration in a particular country permit the use of mixed fish species in food products to be sold on the free market? What is the composition, textural characteristics of the fish species most prominently present in the usual shore by-catch? Does the public, by and large, accept as food products those in which the identity of the raw material has been lost? In other words, must fish be used *qua* fish and not as a food ingredient? These, and many other, questions need knowledgeable and precise answers before strategies in by-catch use are developed and implemented. Questions such as those about price, profit, acceptability, etc. have direct bearing upon all the problems and decisions down the line — indeed to the very shape of the vessel hull.

Conclusions

The proper use of the by-catch for human consumption is an urgent and important problem that must be addressed more vigorously and cooperatively than it has been hitherto; it is a problem that can be solved with the available technologies in a way that makes solutions acceptable and profitable to different local circumstances, wherever the problem arises. It is important to address the problem not only for its own immediate sake but also because local experience and knowledge are needed in the handling of mixed catches of groundfish in preparation for the day when shrimp is overfished, fuel overpriced, and other food dangerously depleted, a day when the by-catch will become a major food harvest.

The whole issue is a typical interdisciplinary complex of interrelated problems requiring the input of experts from many areas of research and development. A systems approach is needed, and we at MIT and, I am sure, many others are ready to assist.

Assessment of the Resources

By-Catch from Shrimp Trawling in Guyanese Waters[1]

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Assessment (July–August 1980) of incidental catches of fish by trawlers operating in Guyanese waters showed that the largest quantities of fish are caught in shallow waters (<15 fathoms), whereas the largest quantities of shrimp are caught in deeper waters (22–39 fathoms). The trawlers continue to fish the shallow waters, however, because highly valued, large white shrimp are only found there. At most, these shrimp constitute 5% of the total catch, a percentage that does not offset the vast quantities of fish currently being wasted as discards. A government program to cut the wastes has required that trawlers land some of their by-catch, but, because the shrimp are the target of the trawlers, the crews process them before the fish — a fact that means the fish may wait hours on deck before being frozen. Because the trawlers operate in shallow waters during the day (and deeper waters at night), the quality of the fish deteriorates badly during this time. These findings suggest that the government should ban shrimping activities in the shallow waters and offer incentives for a fleet to catch groundfish for the by-catch processing project that it has launched.

The waters on the continental shelf near Guyana contain a tropical multispecies fishery, with shrimp or prawns (*Penaeus* spp.) as the target of trawling operations. The fish community associated with these shrimp is diverse and abundant. When such fish are taken as by-catch during trawling operations, they are usually discarded at sea. The Guyanese government, with some IDRC aid, has initiated a by-catch use project that could change current practices. However, it requires information on the raw material that is potentially available as the basis for profitable future developments. Providing these data was the aim of this study; the specific objectives were to:

- Estimate, during one shrimping season, the volume and composition of the by-catch taken by the shrimp fleet and its spatial variation;
- Develop a simple sampling scheme that could be used locally to monitor and eventually estimate the catch volumes seasonally; and
- Interpret the baseline data collected and make recommendations for development of the fishery.

Methods

Commercial catches were sampled at sea, the catch per unit effort (CPUE) was computed for individual species, mean length recorded, and weight-length relations were established for species common in the catch. These data were combined with information about operations of the fleet and records of landings as a basis for estimates of fish by-catch during the months of July and August.

Operations records for all vessels of the fleet do not exist, although short-term records for several vessels were found. Records of fleet size, vessel and gear types, and shrimp landings (volume and composition) were obtained from the Fishery Division of the Ministry of Agriculture, from shrimp-company records, and from the government vessel registry. A data-collection program has since been set up so that information on the operations of individual vessels can be used for future analysis of the spatial variations of by-catch. This program relies on captains from a subsample of the fleet to maintain a daily log while at sea.

Twenty-two commercial catches were sampled during July and August 1980 at compass bearings between 350° and 110° near Georgetown, Guyana, and in depths between 10 and 40 fathoms (18–73 m). Sampling coincided with the areas where the fleet was operating.

[1]Summary of a report prepared, on a consultancy basis, for the International Development Research Centre, Ottawa, Canada; the results were presented by W.H.L. Allsopp at the Consultation.

Sampling technique

Timed trawls, after being brought on board, were allowed to settle until the fish stopped moving. Then they were shoveled into a pile. Thus, the species that had moved to the outside of the unmixed pile were reintegrated. A sample was taken from the perimeter toward the centre of the pile and placed in a plastic basket (the type used on all vessels for handling shrimp). The basket was filled and weighed on a spring balance. (After this operation had been performed several times, the mean weight was calculated and used in subsequent monitoring.)

The basket was then emptied on deck and the shrimp in the sample were headed. The tails were placed in a separate container and weighed. The crew headed the balance of the shrimp catch, and the remaining fish and the shrimp heads were shoveled into baskets, weighed, and discarded. Later, the fish sample was sorted according to species or species group and counted. The lengths of the most abundant and valuable fish were measured. Fresh samples of the measured species were taken from the catch and frozen. The weight–length relationships of these 20 species were determined (weighings to 0.10 g on a double-beam balance). The figures for the sample were extrapolated to the total catch. As a measure of the accuracy of the method, the amounts of shrimp estimated for 21 trawls according to this method were compared with actual amounts obtained, and there was no significant difference ($P = 0.090$).

The numbers of each species or species group in each sample were reduced to CPUE expressed as fish/hour. The CPUE was consistent among vessels in the fleet because the boats are similar in power and design. The CPUE was defined for several communities of fish (the method of defining communities was cluster analysis — the best results from 12 different techniques). Two similarity indices (correlation coefficient and Euclidean distance) were used in both standardized and raw form. Clustering was done with the centroid, averaging, and Ward's minimum variance methods. The decision on which methods to accept as the best groupings of samples (i.e., communities) was based on the method's ability to produce replicated results, correlated to depth.

Within communities, the correlated occurrence of different fish with shrimp was examined with the same 12 clustering techniques. This defined the shrimp–fish associations. As no external criteria (i.e., depth) existed to select the most acceptable clusters containing shrimp and fish, the number of times any of the 12 techniques indicated a specific association was used as the measure of association strength. If all 12 techniques clustered a fish species with the shrimp, that species was given a score of 12 and assumed to be a close association. The size of clusters varied with method. Clusters accepted as representing a group were defined on an arbitrary basis, the goal being to reduce the number of associations to fewer than 20 species. Generally, clusters were well defined and easily interpreted subjectively.

The weight estimates of fish catch were limited to 20 species because of time and resource constraints. Species were selected on the basis of high catches, potential as food (based on size and marketability), current use as food in Guyana, and storage quality. The measured weights and lengths of these species were fitted to the weight–length equation by the methods of Pienaar and Thomson. The mean length of the 20 species was established from as many samples as possible. If the fish occurred in more than one community, the samples were pooled. Most species were restricted in their distribution, concentrating in one depth strata.

The proportion of hours spent fishing the various communities during the rainy season was multiplied by the mean number of monthly landings, the mean hours fished per landing, and the weight CPUE of the fish as a basis for estimates on the catch currently available to the by-catch project.

Results

In January 1980, 148 vessels were operating in the fishery. Owned by 12 individuals or companies, all land their catch at one of three processors in Georgetown: Ocean Guyana Ltd, Guyana Fisheries Ltd, and Georgetown Seafoods. The latter two companies own more than 65% of the fleet. Records show a marked decline in the size of the fleet since 1975 (244 vessels). Since 1977, foreign vessels have been excluded from Guyana's territorial waters.

Shrimping continues throughout the year, and, although there is a marked difference in the average number of landings per month,


Although the fish are stored in refrigerated holds, they may sit on deck for as long as 3 hours beforehand.

the variations follow no chronological trend. The number of landings per month for July and August was 124 (8.2 SD, n = 3) and 113 (3.3 SD, n = 3), respectively. Number of hours fished per trip varies, but, during 13 trips spanning 1980, boats fished an average 465 hours (82 SD). Area fished also varies. Shallow-water (<15 fathoms deep) fishing is generally conducted during the day, and night fishing concentrates in waters 25–40 fathoms deep. Vessels from Georgetown Seafoods are inclined to operate 24 hours, even when inshore fishing is unproductive; they carry more fuel than do Guyana Fisheries vessels, which fish only the offshore grounds when inshore operations are marginal.

Main nets are towed from 1 to 12 hours, and trips last from 3 to 6 weeks, depending on catch, fuel supplies, and mechanical breakdown. Highly valued food fish are retained, but most fish are discarded at sea. The shrimp catch is headed, washed, and soaked in a seawater solution of anhydrous sodium metabisulfite before being frozen. This operation takes 2–5 hours and has priority over fish processing.

Although efforts may be concentrated in a specific area in the short term, they are generally random and along the entire Guyana coast. Although total effort has declined, landings have not declined — an increase in CPUE.

Shrimp landings are lowest during November, December, and January, although the number of landings per month remains fairly constant over the year. Landings increase steadily from February to May then sharply decrease in June, increasing again in July.

The by-catch

The by-catch fish community closest to shore occurs between 9 and 11 fathoms (the 10-fathom community); moving away from shore, one finds a community between 14 and 15 fathoms deep (15-fathom community). The 25-fathom community extends from 22 to 25

Sorting the by-catch.

fathoms, and the most offshore community ranges from 32 to 39 fathoms (the 35-fathom community). During May, June, July, and August the 10-fathom community was fished for 49% of the time, the 15-fathom community 19%, the 25-fathom community 15%, and the 35-fathom community 17% (where n = 946 hours of data collected during the 2 years).

Within communities, 95 species or species groups were identified, but not all species occurred in each community. Species diversity generally increased with depth. However, this finding may reflect differences in the amount of time fished: the samples closest to shore came from short trawls, necessitated by large catches, and, hence, may be artificially less diverse (Table 1). Because clustering was by correlated occurrence, the associated species may have widely different absolute abundances. Many of the species occurred only sporadically in the samples and are of little use for industrial production. The species included marketable, less-marketable, and unmarketable fish (Table 2). The marketable species were those that are already valued in the by-catch, those of sufficient abundance and size to make an immediate contribution, and those valued in other areas. The less-marketable species were those that are less abundant, have poor storage qualities, are small, or have only limited use in other areas. The unmarketable species were poisonous fish or those suspected of being poisonous; they deserve mention, as their presence may be of concern in bulk use of unsorted catches. The CPUEs demonstrated that the abundance of fish declines as the depth of water increases, although the reverse is true for poisonous species.

In contrast, shrimp abundance is lowest in the communities close to shore (9–15 fathoms deep) and greatest in the two offshore communities (22–39 fathoms deep). This finding is even more pronounced than is apparent in the data presented here because the inshore-shrimp count includes seabob (*Xiphopenaeus* spp.), which are small and are discarded. All offshore shrimp are kept. This fact leads to

Table 1. Scores from 12 techniques of cluster analysis of the strength of association between fish species (or species groups) and shrimp.[a]

10-fathom community		15-fathom community		25-fathom community		35-fathom community	
Species	Score	Species	Score	Species	Score	Species	Score
Prionotus rubio	12	*S. plagiusa*	10	*Haemulon steindachneri*	9	*Pristipomoides macrophthalamus*	7
Synodus spp.	12	*Synodus* spp.	9	*P. rubio*	9	Mullids	6
Dasyatis sayi	11	*Dactylopterus volitans*	7	*Rhomboplites aurorubens*	6	*S. brasiliensis*	6
Peprilus paru	9	*Diplectrum* spp.	6	*Acanthostracion guadricornis*	5	*Prionotus stearnsi*	6
Ogcocephalus spp.	8	*E. argenteus*	5	*Haemulon aurolineatum*	4	*Synodus* spp.	6
Gymnarchirus spp.	8	Ophidids	4	*Ogcocephalus* spp.	4	*Monacanthus* spp.	5
Cynoscion virescens	5	*Orthopristis ruber*	3	*Bellator militaris*	4	*Sphoeroides* spp.	5
Pellona harroweri	3	*C. nobilis*	3	*Porichthys porosissimus*	3	*Halutichthys* spp.	4
Oligoplites saurus	2	*Sphyraena guachancho*	1	*Lutjanus synagris*	3	*Ogcocephalus* spp.	4
Diapterus rhombeus	2			*S. guachancho*	3	*P. porosissimus*	3
Cynoscion arenarius	2			*Lutjanus aya*	3	*B. militaris*	2
Ctenosciaena gracilicirrhus	2			*D. rhombeus*	3	*Ariomma regulus*	2
Odontognathus surinamensis	2			*Albula vulpes*	3	*Chilomyctrus* spp.	2
Chloroscombrus chrysurus	1			*D. volitans*	3	*Balistes* spp.	2
Eucinostomas argenteus	1			*Phrynelox scaber*	3	*Lagocephalus laevigatus*	2
Conodon nobilis	1			*Monacanthus* spp.	1	*P. rubio*	1
Haemulon plumeri	1			*Diplectrum* spp.	1	*Chaetodipterus faber*	1
Polydactylus octonemus	1			*Scorpaena brasiliensis*	1	*Rachycentron canadum*	1
Symphurus plagiusa	1			*Halutichthys* spp.	1		
Menticirrhus americanus	1						

[a]The score indicates how many of the 12 techniques showed an association between the particular species (or species group) and the shrimp.

Table 2. Mean CPUE (number of fish/hour for boats with two nets), shrimp production, and fish/shrimp ratios.

	Community							
	10-fathom		15-fathom		25-fathom		35-fathom	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Marketable								
Selene setapinis	4888	8659	16	26	0	0	4	9
Macrodon ancylodon	3570	1451	0	0	0	0	0	0
Harengula jaguana	2377	1555	2	3	0	0	0	0
Bagre bagre	1436	437	0	0	0	0	0	0
C. nobilis	121	135	20	20	0	0	0	0
Pomadasys carvinaeformis	112	163	38	48	0	0	0	0
Menticirrhus americanus	77	154	45	4	0	0	0	0
C. virescens	63	31	0	0	0	0	0	0
Micropogon furneri	58	67	0	0	0	0	0	0
Genytremus sp.	53	61	0	0	0	0	0	0
Nebris microps	48	72	0	0	0	0	0	0
Bothids	0	0	490	210	646	196	251	252
D. volitans	0	0	9	9	452	362	629	437
E. argenteus	0	0	10	7	79	49	5	8
O. ruber	0	0	64	55	33	61	0	0
R. aurorubens	0	0	0	0	58	24	16	25
H. aurolineatum	0	0	0	0	22	18	3	4
H. steindachneri	0	0	0	0	44	29	1	2
Priacanthus arenatus	0	0	0	0	6	8	23	23
P. macrophthalamus	0	0	0	0	0	0	15	25
Fish/shrimp ratio	**13.12:1**		**1.71:1**		**0.68:1**		**0.48:1**	
Less marketable								
P. harroweri	2576	3798	0	0	0	0	0	0
Stellifer rastifer	1833	1086	0	0	0	0	0	0
O. surinamensis	1174	988	0	0	0	0	0	0
Stellifer microps	694	274	0	0	0	0	0	0
Trichiurus lepturus	628	655	0	0	1	2	5	1
Isopisthis parvipinnis	582	298	0	0	0	0	0	0
Anchoa spinifer	505	358	0	0	0	0	0	0
C. gracilicirrhus	394	788	35	40	15	25	0	0
Bairdiella ronchus	167	263	29	58	0	0	0	0
Arius spp.	154	134	0	0	0	0	0	0
P. octonemus	118	123	2	3	0	0	0	0
D. rhombeus	77	154	0	0	5	1	0	0
C. arenarius	77	154	43	40	5	6	1	2
C. faber	64	88	24	36	0	0	2	1
Paralonchurus brasiliensis	55	69	0	0	0	0	0	0
P. rubio	10	19	576	317	58	30	13	18
C. chrysurus	0	0	90	114	2	3	0	0
P. porosissimus	0	0	228	103	93	29	191	184
B. militaris	0	0	0	0	63	55	67	51
Mullids	0	0	49	28	19	12	73	75
Fish/shrimp ratio	**9.46:1**		**2.65:1**		**0.12:1**		**0.16:1**	
Unmarketable								
Sphoeroides spp.	0	0	6.1	4.0	17.0	13.0	28.0	13.0
Chilomyctrus spp.	0	0	0.5	1.0	5.8	3.3	0.4	1.1
S. gauchancho	0	0	2.5	3.4	0.5	1.0	0	0
Shrimp	**976**	**576**	**406**	**140**	**2110**	**495**	**1968**	**924**

wide disparities in the number of fish taken as by-catch for each shrimp kept. By-catch is much greater within the 10-fathom grounds.

The decline in abundance of fish in the deeper communities is duplicated by a decline in weight. Average weight of fish caught each hour from the community nearest shore was twice that from the three offshore communities. Estimates of the monthly weight of useful fish taken as by-catch give some idea of the potential landings (Table 3). The means used in these estimates included error estimates when possible. These figures indicate the vast quantities of useful fish that are discarded as by-catch. Virtually all of this amount during the June–August rainy season is caught between 9 and 14 fathoms where large white shrimp are found. During this study, no white shrimp were observed outside 15 fathoms; they are highly valued but rarely exceed 5% of total production and result in the greatest waste of usable by-catch.

Discussion

The waste of the by-catch in the Guyanese shrimp fishery is enormous and was probably far greater before the national fleet was reduced and foreign vessels were excluded from the exclusive economic zone. Stable shrimp catches indicate highly productive stocks. Although there are no records on the by-catch in the past, fish-stock productivity may be assumed to be high, as it is in other tropical areas.

In waters deeper than 15 fathoms, few useful or even marginally usable fish are found, although these areas are the richest in shrimp and contain the greatest number of unmarketable fish. Thus, the inshore grounds are the most important source of input for any fish-processing facility.

At present, the grounds closest to shore are exploited by a large but poorly equipped artisanal fishery (Chakalall 1980). However, the long, gently sloping, continental shelf puts the 15-fathom grounds well beyond the reach of the artisans. Shrimp trawlers seldom operate in waters less than 9 fathoms deep, and, consequently, a large, relatively unfished band of water exists between the limits of the two fisheries. By-catch from the offshore edge of this band is the richest on the shelf and promises great potential.

Farther offshore, in the 15-, 25-, and 35-fathom communities, the catch of fish is much smaller, and the species tend to be small and spiny, dominated by dactylopterids, triglids, batrachids, and many small (<10 cm) bothids. The main food resources available are lutjanids and pomadasyids. The snappers that are found in this area are small species (e.g., *Rhomboplites* sp.). Grunts are widely used as food throughout the world and are found at all depths; however relatively insignificant numbers are taken at depths of 15 fathoms or more.

Table 3. Potential landings of the 20 desirable fish species. The estimates assume an average 465 fishing hours for each landing and an average 124 landings in July and 113 in August. The hours spent fishing are assumed to be distributed among the communities as follows: 10-fathom 49%; 15-fathom 19%; 25-fathom 15%; and 35-fathom 17%. Common local names are in parentheses.

Species	Potential monthly landings (t/month) July	August
M. ancylodon (bangamary)	8482	7729
S. setapinis (moonshine)	5322	4850
H. jaguana (herring)	2587	2357
B. bagre (catfish)	2460	2241
M. furneri (croaker)	489	446
M. americanus (whiting)	208	190
N. microps (butter fish)	194	176
C. nobilis (annafolk)	188	171
D. volitans (gunnard)	133	121
Bothids (flounders)	128	116
C. virescens (trout)	127	116
P. carvinaeformis (grunt)	121	111
Anisotremus virginicus (annafolk)	56	51
E. argenteus (mojarra)	29	27
Q. ruber (grunt)	27	25
H. steindachneri (grunt)	25	23
R. aurorubens	17	16
H. aurolineatum (grunt)	14	12
P. arenatus	13	12
P. macrophthalamus	3	3

As inshore grounds are capable of producing as much raw material as the by-catch project can handle, they are the logical area on which to concentrate. At present, the by-catch receives second priority to the more valuable shrimp. Consequently, fish remain on deck for hours before receiving attention. This practice is especially a problem near shore because fishing in this area is during daylight when the hot sun speeds spoilage.

The portion of the by-catch that is retained has deteriorated markedly by the time it is finally frozen. If fish are to be kept in good condition, shipboard processing will have to be improved.

One means of obtaining the by-catch in good condition and stopping the waste of fish resources is to ban shrimp fishing within shallow waters (<15 fathoms) and employ small trawlers to collect fish near shore. This approach would obviate the need for catch-transfer methods needed by collector-boat systems. The impact on shrimpers would probably not be significant because the most productive shrimp grounds are off shore. It would eliminate white shrimp from the catch, but they represent only 5% or less of the catch. It would also reduce brown-shrimp production, although the amount is unknown and should be examined.

Collection of samples encompassing a more complete range of depths and a larger area of the coast than was possible in this study is needed so that the fish communities and their spatial variability can be better understood. The fishery is, at present, in an advanced developmental stage and will need a strong data base in the future when more stringent management becomes necessary. This can only be obtained by continued data collection and analysis. In the meantime, some recommendations can be made on the basis of the existing data:

- The by-catch project should continue to concentrate on processing fish from the inshore community and should consider expanding to include catfish, herring, and moonshine.
- A policy of reducing the waste of the by-catch could be easily implemented by the government if it prohibited shrimping in waters shallower than 15 fathoms during the rainy season. The effects of continued wastage can only be determined by a long-term monitoring program.
- Biologic data collection should continue for at least 2 person-years, with increased sample size and coverage of all seasons. In fact, if the effects of wasting the by-catch are to be determined, data collection should continue indefinitely.
- To improve the quality and regularity of fish inputs to the processing facility, the authorities should provide incentives for small trawlers to target specifically on fish in shallow waters near shore.
- Biologic sampling should be done from as many different vessels as possible so that catch statistics reflect a wide range of operating strategies.
- The captains' log program should be continued so that the fleets' distribution among the fish communities can be accurately delineated.
- Data collected for 2 person-years should be subjected to an in-depth analysis.

Fish Discards from the Southeastern United States Shrimp Fishery

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*Magnitude and species composition of fish by-catch are described for the Gulf of Mexico and south Atlantic shrimp fleets. By-catch estimates for the Gulf were 15 times those for the south Atlantic. Highest estimates occurred in the north–central and northwestern Gulf and in the south Atlantic off the North Carolina and Georgia coasts. Catch compositions varied at the species level; however, Sciaenidae was the dominant family for both the Gulf and the south Atlantic. Gulf fauna included estuarine-dependent species in subtropical environs and estuarine-independent species in tropical environs. Dominant species included Atlantic croaker (*Micropogon undulatus*), spot (*Leiostomus xanthurus*), and sand seatrout (*Cynoscion arenarius*). Compositions were relatively similar throughout the south Atlantic, with spot, Atlantic croaker, and weakfish (*Cynoscion regalis*) making major contributions.*

The shrimp industry is one of the most important fisheries in the United States. Shrimp ranked first in value and either second or third in volume of all U.S. fisheries between 1971 and 1975. The Gulf of Mexico and south Atlantic regions play a significant role in the nation's shrimp industry, accounting for approximately 53.0% and 7.1% of the total landings, respectively. Three species provide the majority of landings in both regions. Catch for the Gulf region includes brown shrimp (*Penaeus aztecus*) 55%, white shrimp (*P. setiferus*) 30%, and pink shrimp (*P. duorarum*) 13%. For the south Atlantic region, the figures are white shrimp 63%, brown shrimp 30%, and pink shrimp 6%.

The primary gear used in the Gulf and south Atlantic shrimp fisheries is the otter trawl, a nonselective bottom net that incidentally catches numerous fish and other invertebrates. Although edible-sized fish are retained for food, the majority of the by-catch, which consists of fish weighing less than 0.25 kg, is discarded at sea. Most discards probably do not survive long after the stress inflicted during trawling and the time on deck during sorting.

Finfish mortalities induced by the Gulf and south Atlantic shrimp fleets have recently gained increased attention. Representatives of the red snapper and groundfish fisheries are concerned about the effects of this waste on the ability of the stocks to rebuild. In 1972, the Pascagoula Laboratory initiated a shrimp fleet by-catch program with objectives to estimate the magnitude and species composition of the finfish by-catch of the northern Gulf of Mexico shrimp fleet. In this paper, I briefly summarize findings of that program and, through a literature review, provide similar estimates for the south Atlantic fleet.

Methods

The shrimp fleet by-catch program acquired data from samples of commercial catches and from analysis of information collected by research vessels. Sampling of the commercial catches was performed by contractors who placed observers aboard the shrimp vessels. The data from the research vessels R/V *George M. Bowers* and FRS *Oregon II* were for stations where commercial shrimp concentrations occurred; the stations were selected by a method described elsewhere (Pellegrin et al., in preparation).

Samples equal to at least 10% of the total catch were taken from each trawl station, sorted by species and identified, counted, and weighed. Mean fish/shrimp ratios were computed by area (Fig. 1) and multiplied by estimates of annual shrimp landings (averaged from data for 1971–75) for the respective areas. Species compositions were computed as percents by weight. Percentages of 10 dominant fish species were multiplied by the

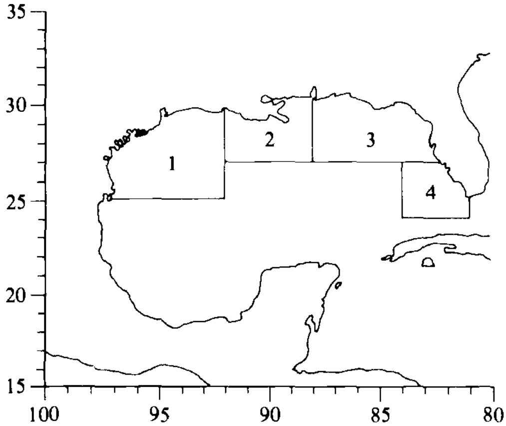

Fig. 1. *Four geographical subareas of the Gulf of Mexico region.*

total by-catch estimates as a calculation of the total by-catch of the individual species.

Catch compositions, fish/shrimp ratios, and total-landing estimates for the south Atlantic either were taken directly from the literature or were modified from the literature so that they conformed with the format used in this study.

Results

Keiser (1977b), in a report on the incidental catch by commercial shrimp trawlers of the south Atlantic states, used fish/shrimp ratios from published and unpublished reports for estimates of by-catch. Because of the variability of data, he used median values that were multiplied by total shrimp landings to estimate total fish by-catch (Table 1).

Estimates of species compositions off North Carolina were taken from Wolff (1972, cited by Keiser 1977b) and were converted to percent by weight of the total by-catch (including invertebrates other than crabs). Catch compositions of Wolff's data were approximately 82.4% fish, 15.7% shrimp, and 1.9% other invertebrates.

Species compositions by weight for the total by-catch for South Carolina are given by Keiser (1977b). However, only species of the fish by-catch are listed by him (1976) in his report on the incidental catch of the South Carolina shrimp fishery. I estimated by-catch for individual fish species by multiplying percent compositions from the Keiser 1976 report by the estimated total fish by-catch for South Carolina (Table 2). Keiser (1977b) cites species compositions of Georgia shrimp-trawl samples from Knowlton (1972). I determined by-catch estimates for 10 dominant fish species by multiplying Knowlton's percent compositions by the estimated annual fish by-catch for the Georgia coast. Species composition data from by-catch samples on a weight basis were unavailable for the Florida northeast coast shrimp fishery. Keiser (1977b) does, however, list species compositions (from Anderson 1968) as percents by number.

My colleagues and I (Pellegrin et al., in preparation) divided the northern Gulf of Mexico into four study areas (Fig. 1) and computed mean fish/shrimp ratios and fish species compositions for the respective areas. These areas were defined on the basis of fish and shrimp densities. Area 1 was characterized by relatively low fish and high shrimp concentrations, and area 2 by both high fish and high shrimp concentrations. Moore et al. (1970) found fish densities to be two to five times

Table 1. Estimated annual fish by-catch for south Atlantic (Keiser 1977b) and Gulf of Mexico (Pellegrin et al., in preparation).

Area	Fish/heads-on shrimp ratios	Number of samples	Mean annual shrimp landings (t, heads-on)	Estimated annual fish by-catch (t)
South Atlantic				
North Carolina coast	4.0:1	59	2883	11532
South Carolina coast	1.6:1	280	3935	6296
Georgia coast	2.6:1	184	3600	9360
Northeastern Florida coast	3.8:1	(unknown)	1647	6259
Gulf of Mexico				
1	6.3:1	478	28118	177143
2	14.4:1	824	17782	256061
3	15.9:1	29	2864	45538
4	4.2:1	146	7150	30030

Table 2. Comparison of fish species compositions in the by-catch (t) for the south Atlantic and Gulf of Mexico regions.[a]

Species	South Atlantic coast			Gulf of Mexico[e]			
	South Carolina[b]	Georgia[c]	North Carolina[d]	Area 1	Area 2	Area 3	Area 4
Micropogon undulatus	2791	356	1956	35077	115953	3233	–
Leiostomus xanthurus	4463	2253	2620	5876	17701	15483	–
Cynoscion arenarius	–	–	–	8547	16674	1821	–
Nonfood fish flounders	357	–	–	15847	–	911	2093
Cynoscion nothus	–	–	–	11573	5643	–	–
Synodus foetens	230	–	–	9437	6670	–	777
Calamus sp., *Stenotomus* sp.	196	–	–	–	13339	–	–
Diplectrum sp.	–	–	–	5520	–	2368	4546
Prionotus rubio	–	–	–	–	10518	–	–
Trichiurus lepturus	–	–	262	–	8722	–	–
Arius felis	–	143	309	–	8466	–	–
Polydactylus octonemus	–	–	–	8724	–	–	–
Peprilus burti	–	–	–	6410	–	1048	–
Lagodon rhomboides	322	–	–	–	–	–	5952
Trachurus lathami	–	–	–	4986	–	–	–
Prionotus scitulus	–	–	–	–	–	3416	1526
Orthopristis chrysoptera	969	–	–	–	–	2231	747
Chloroscombrus chrysurus	–	–	–	–	3078	–	–
Haemulon aurolineatum	–	–	–	–	–	–	1764
Alutera schoepfi	–	–	–	–	–	1048	599
Cynoscion regalis	450	137	646	–	–	–	–
Brevoortia tyrannus	–	574	655	–	–	–	–
Menticirrhus sp.	161	231	833	–	–	–	–
Eucinostomus gula	–	–	–	–	–	–	1107
Anchoa hepsetus	–	–	–	–	–	775	–
Stellifer lanceolatus	–	275	431	–	–	–	–
Skates and rays	–	325	336	–	–	–	–
Paralichthys sp.	462	–	–	–	–	–	–
Urophycis regius	–	343	–	–	–	–	–
Larimus fasciatus	–	–	299	–	–	–	–

[a]Absence of data indicates species did not occur in top 10 for respective localities.
[b]Keiser 1976 and 1977b.
[c]Knowlton 1972.
[d]Wolff 1972.
[e]Pellegrin et al. in preparation.

greater off the Louisiana coast (approximately area 2) than off the Texas coast (area 1). Louisiana and Texas also annually lead the Gulf states in volume of shrimp landed. Area 3 was characterized by both low fish and low shrimp concentrations. Gutherz and Thompson (1977) noted that sciaenids (the dominant groundfish family by weight in the northern Gulf) decreased greatly east of Mobile Bay, Alabama. Much of area 3 is considered untrawlable; therefore, shrimp landings for area 3 were lower than the landings for areas 1, 2, and 4. Area 4 was characterized by greater shrimp landings than area 3 but lower fish densities. The faunal composition also changes in area 4 from semitropical, as found in areas 1 through 3, to tropical. The overall fish/shrimp ratio in the by-catch of the Gulf is 9.1 : 1, and the total estimated by-catch is 5.1×10^5 t.

Discussion

The two largest annual fish by-catches of the south Atlantic region occurred off the North Carolina and Georgia coasts where an estimated 1.1×10^4 t and 9.4×10^3 t were taken, respectively. By-catch estimates were much lower for northeast Florida and South Carolina where 6.259×10^3 t and 6.296×10^3 t were taken, respectively.

Species compositions were relatively similar throughout the south Atlantic region

(Table 2); sciaenids dominated, with several species making significant contributions. Spot ranked number one for three states, whereas Atlantic croaker ranked either second or third. Other sciaenids included weakfish, kingfish (*Menticirrhus* sp.), star drum (*Stellifer lanceolatus*), and banded drum (*Larimus fasciatus*). Atlantic menhaden (*Brevoortia tyrannus*) contributed significantly off the coasts of South Carolina and Georgia where it ranked second and fourth, respectively.

For the entire south Atlantic region, an estimated 3.3×10^4 t of fish by-catch were harvested annually by the shrimp fleet. Five of the top 10 fish species were sciaenids, constituting 53.1% of the total fish by-catch. Dominant sciaenids included spot, Atlantic croaker, and weakfish. Other dominant species included Atlantic menhaden and pigfish (*Orthopristis chrysoptera*). The fish/shrimp ratio for the region was 2.8 : 1.

The two largest annual fish by-catches in the Gulf of Mexico occurred in areas 1 and 2. Fish captures were significantly smaller in areas 3 and 4.

Species compositions changed markedly across the Gulf region (Table 2). Sciaenids dominated in areas 1 through 3 but did not occur in the top 10 species of area 4. An estimated 6.1×10^4 t of sciaenid by-catch were harvested annually in area 1. Atlantic croaker dominated the catch, followed by shoal flounder (*Syacium gunteri*) and silver seatrout.

The centre of the northern Gulf of Mexico sciaenid population appears to occur in area 2, as an estimated 1.6×10^5 t were harvested annually (equal to about 60.8% of the total fish by-catch). Sciaenids were represented by the top three species in this area, with Atlantic croaker exerting the greatest influence.

Although sciaenids dominated the species composition of area 3, they were not as abundant as in areas 1 and 2. Spot replaced Atlantic croaker as the most dominant species, with leopard searobin (*Prionotus scitulus*) also contributing significantly to the catch.

The annual estimate of total fish by-catch for the Gulf region was more than 15 times that of the south Atlantic region. This probably reflects the vast estuarine complex of the Gulf of Mexico centred on the Mississippi River delta. Gunter (1967) described the area as being one of the largest estuarine regions of the North American continent and one of the most productive fishery areas of the world. Gulf-wide, about 90% of the commercial catch and 70% of the recreational catch are made up of estuarine-dependent species (Lindall and Saloman 1977). Inspecting the species compositions of the by-catch for the Gulf region reveals that most species are indeed estuarine-dependent. This extensive estuarine environment would explain the overall greater productivity of the Gulf region in terms of both fish and shrimp.

Although sciaenids dominated the species compositions of both regions (53.1% of the south Atlantic and 43.4% of the Gulf), individual species components varied greatly. Spot dominated the south Atlantic region followed by Atlantic croaker and weakfish. Other dominant species included Atlantic menhaden and kingfish.

In the Gulf region, Atlantic croaker dominated the catch, followed by spot and sand seatrout. Inshore lizardfish (*Synodus foetens*) and longspine porgy (*Stenotomus caprinus*) also made major contributions.

Yields and Composition of By-Catch from the Gulf of California

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We carried out systematic studies of the variability in the yield and composition of by-catch from shrimp trawling in the Gulf of California to assess the potential of the catch as a food resource. Throughout the 2-year study, the mean by-catch/shrimp ratio for commercial operations was 9.8 : 1, with an average by-catch yield of 90 kg/hour. However, the yields of by-catch during the warm seasons were much greater than those obtained in colder periods. About 105 species of fish from 52 families were observed in samples recovered during the study. Of these, 9 species or groups of closely related species constituted 65% of the fish examined. Demersal fish predominated, and pelagic species were noted relatively infrequently. Although the size of the fish ranged from 6 cm to 65 cm, the vast majority measured 8–14 cm. These fish are too small for normal marketing and are difficult to clean. Moreover, the frequent observation of the bullseye puffer (Sphoeroides annulatus), *a toxic fish, in the by-catch from the region indicates the necessity for caution in the use of the resource for human consumption.*

The initial phase of the ITESM/TPI shrimp by-catch program included an evaluation of the variability in yield and composition of the resource in the Gulf of California near northwestern Mexico. This basic information was required before any attempts could be made to use the resource. Existing data from the region were sparse, although previous reports had suggested that the Gulf of California by-catch was a significant fishery resource (Chavez and Arvizu 1972; Rosales 1976). Our studies were undertaken aboard commercial shrimping vessels in the region between August 1977 and March 1979, i.e., two consecutive fishing seasons. The by-catches contained in a total 365 shrimp trawls were examined (Young and Romero 1979; Perez Mellado 1980).

Methods

Collection of shrimp by-catch was carried out along the continental shelf of the coasts, corresponding to the states of Sonora and Sinaloa, from Puerto Peñasco in the north to Macapule in the south. Some sampling was also undertaken along a small section of the coast of Baja California between Santa Rosalia and Muleje. Short voyages (2–5 days) were completed aboard different commercial vessels registered at Guaymas, Sonora. More lengthy voyages (up to 3 weeks) were undertaken aboard the research vessels Marsep IV and Marsep V of the Centro de Educación en Ciencia y Tecnología del Mar (CECITEM). The parameters recorded at sea for each trawl were sampling date and time, duration of tow, depth of trawl, location, surface-water temperature, weight of shrimp, and weight of by-catch.

Shrimp was weighed routinely by the crew, and the weight of by-catch was assessed from the total volume of the catch: the trawl contents were placed in baskets, weighing about 20 kg when filled with fish, and the total weight was calculated from the number of containers required for the entire catch. Samples of by-catch were collected immediately after the contents of the trawl net were released on deck. Approximately 10% of the catch was sampled at random and stored in sacks, either frozen or iced, for subsequent study in the laboratory. Each fish recovered in the trawl samples was identified according to existing taxonomic keys and the personal experience of one of our team (L.T.F.).

Results

During the study, a total 1.17×10^4 kg shrimp and 1.15×10^5 kg by-catch fish were landed aboard the vessels. The ratio of by-catch/shrimp was, therefore, 9.83 : 1. As the total trawling time was 1274.4 hours, the capture rates for shrimp and by-catch were 9.18 kg/hour and 90.27 kg/hour, respectively. The data varied considerably in different trawls. Nevertheless, 95% of the portions measured fell within the range 1.3 : 1–36 : 1. The quantities of by-catch in the trawls fell toward the end of the season (February–April). This variation appears to reflect changes in the water temperâture, the higher water temperatures (existing during the initial phase of the shrimping season) promoting increased yields of by-catch from shrimp fisheries. The results support data that indicate by-catch is more significant in warm waters than in cooler areas.

Previous observations had indicated that the resource primarily comprised teleosts, i.e., finfish (Chavez and Arvizu 1972), and this finding was confirmed in our study, the by-catch generally being 70–100% finfish. The remainder included mainly small crustaceans, molluscs, elasmobranchs, and sponges. Within the teleost group, 105 species or groups of species from 52 families were identified in the samples recovered from shrimp trawls (Young and Romero 1979; Perez Mellado 1980).

When the water temperature was increased during the warm months, not only were the by-catch yields larger but also the variability in by-catch composition was greater than during the cooler months. The diversity of finfish recovered in shrimp trawls depends both on the variety of species available and on the low selectivity of the trawling equipment. Despite the diversity, eight genera accounted for 65–70% of all fish recovered in by-catch samples: *Citharichthys* (flatfishes), *Diplectrum* (cabaicuchos), *Orthopristis* (grunts), *Scorpaena* (scorpion fish), *Synodus* (lizard fish), *Eucinostomus* (mojarras), *Porichthys* (midshipmen), and *Pseudopenaeus* (goat fish).

These are all small, lean demersal fish. Oily, pelagic fish are sometimes trapped in the trawl net as it is raised to the water's surface, and a few pelagic species, such as Pacific mackerel (*Scomber japonicus*), Pacific sardine (*Sardinops sagax caerulea*), and anchovy (*Anchoa* sp.) were observed in our study, although their frequency was relatively low.

Mean weights and mean lengths of by-catch fish varied from 7 g to 490 g and 6 cm to 65 cm respectively. However, more than 90% of the fish weighed less than 50 g and measured less than 20 cm. These data demonstrate that the majority of the fish in the trawls from the Gulf of California are well below the size normally considered suitable for food-grade fish. The few commercially valuable fish that were observed during the study were selected on board by the shrimpers for sale when the boat returned to shore. Observations made so far suggest that the percentage of commercial-grade fish in the by-catch from the Gulf of California is only about 2–5.

Fortunately, these studies have indicated that the resource predominantly comprises species that are acceptable for human consumption. Nevertheless, the bullseye puffer (*Sphoeroides annulatus*) was observed regularly during the study, and this species contains a potent neurotoxin, tetrodotoxin, in its liver and viscera. Recent studies in Mexico have confirmed the extreme toxicity of this puffer species (R.F. Crampton, unpublished data). Poisoning may be avoided by careful gutting of the fish, but such species must be separated from material to be used in human food. Puffer fish can be easily recognized and eliminated on board or during examination of the by-catch on shore.

Conclusions

The potential by-catch in the region is 1.6×10^5 t/year, the finfish portion being about $1.10–1.25 \times 10^5$ t/year. The variation in yield caused by changing water temperatures underlines the difficulty in extrapolating results to other regions.

Despite the fact that the by-catch comprises a complex mixture of marine organisms, the predominance of fish species from eight genera, which have flesh of similar chemical composition has been demonstrated. If the species varied greatly, it would be difficult to standardize products.

An important finding from the study is that Gulf of California by-catch consists of small fish. The incidence of fish of commercial type and size appears to be minimal, such that by-catch use in the region means more than just promoting increased recovery and sale of whole or filleted fresh fish. In this case, nontraditional techniques are required to convert by-catch fish into acceptable forms for human consumption.

These studies provide biological data that can serve as a basis for industrial processing.

We are indebted to the fishing cooperatives and shrimpers of Guaymas without whose cooperation this study would not have been possible. We also much appreciate the assistance of CECITEM of the Secretaria de Educación Pública (SEP) for providing the use of the shrimping vessels Marsep IV and Marsep V for the sampling voyages in this study.

Processing at Sea

Handling Mixed Catches

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A mechanical fish grader–icer has been developed by the Technological Laboratory of the Ministry of Fisheries in Denmark. The equipment was designed for use on shrimp trawlers; it moves the catch from the deck to the fish stowage in the hold while it grades the fish for either industrial (animal feed) or food use and ices them. At present, the equipment is being tested aboard commercial trawlers in the North Sea.

Danish trawl fisheries in the North Sea vary greatly according to season and locality. Some catches are uniform, containing mainly one species, such as sand eel, but for most of the year, trawl catches contain a variety of species and sizes. Most small fish like sand eel and Norway pout are used in animal feed only, whereas larger species should be handled as food fish.

Fishing takes up many of the working hours of the small crew of Danish trawlers, leaving little time for the handling, chilling, and stowage of the catch. Mechanical equipment for catch handling has so far been very limited or nonexistent. The handling of the large mixed trawl catches has been hindered by the lack of personnel and auxiliary equipment on board.

When industrial fish (small whole fish intended for reduction to meal) are stowed in the hold without effective chilling, the atmosphere within the hold may become dangerous within a few days. The fish undergoing spoilage consume oxygen and emit dangerous gases, such as carbon dioxide and hydrogen sulfide, which accumulate in the lower part of the hold. In 1976, such gases and the lack of oxygen caused the deaths of three Danes working in the holds of North-Sea trawlers loaded with industrial fish.

Chilling of industrial fish is essential not only for security and health reasons but for maintaining the fish quality and yield. Large-scale tests in the North Sea showed that Norway pout, stored in ice for 6 days lost 6% in weight, whereas the weight loss at ambient temperature, 15°C, was 27%. The "blood water" lost at ambient temperature deprived the catch of 74% of its oil and 14% of its original protein content. During storage at ambient temperature, some of the remaining oil hydrolyzes to free fatty acids and some of the remaining protein breaks down to volatile compounds that have no nutritional value and that cause air pollution around the fish harbour and reduction industries.

Large trawl catches coming on deck at a rate of 1–2 t/minute to be stowed in fish holds 3–4 m deep cannot be iced effectively without the use of mechanical equipment specially designed for this purpose.

Another problem in the handling of large mixed trawl catches has been the grading into industrial fish and food fish. Without mechanical-grading equipment, only a fraction of the food fish, mainly the largest fish, can be retrieved. Thus, at times, substantial quantities of smaller food fish remain among the industrial catch.

The Technological Laboratory of the Danish Ministry of Fisheries has participated in the development of improved catch handling. Equipment (Fig. 1) comprises a receiving box on deck equipped with a conveyor continuously feeding a rotating drum. This drum grades the fish into two categories — industrial, which includes fish less than 35 mm thick, and food, which includes thicker species.

The receiving box is equipped to remove the few large fish and other large objects before the catch enters the conveyor and the grader. The box may receive portions of up to 2 t of fish, which are converted to a continuous flow of up to 1200 kg/minute. The food fish pass through the length of the cylinder, and the industrial fish fall through the coil into a trough equipped with a continuous supply of small pieces of ice to chill the fish to 0°C and maintain this temperature until the fish are landed. A conveyor running along the trough takes the mixture of fish and ice to a vertical conveyor that lifts the mixture 2 m above the

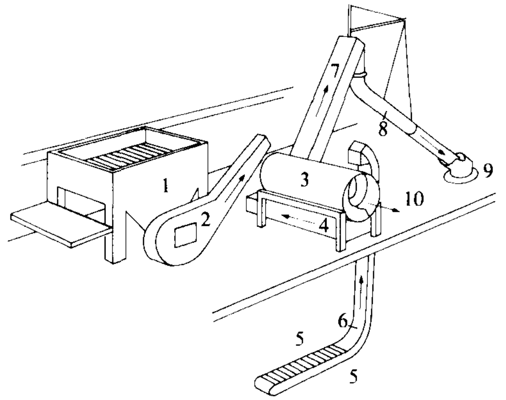

Fig. 1. *Catch-handling equipment: (1) receiving box covered with a grid of heavy steel bars for protection against the inclusion of large objects; (2) conveyor taking the fish continuously into the grader (3) at a rate of up to 1200 kg/minute; (3) rotating grader separating the small industrial fish from the food fish; (4) trough receiving the small fish and ice, coming from the hold (5) via the conveyor (6); (5) ice store in the hold from which the ice is fed into the horizontal part of the conveyor (6); (6) ice conveyor built into the central gangway of the fish hold (the horizontal part is covered with a safety grid of bars spaced at about 80 mm, which allows the broken ice to fall into the conveyor; the vertical part brings the ice into the mixing trough [4] under the grader [3]; the conveyor speed is adjustable, with a capacity of 0–250 kg/minute); (7) conveyor lifting the mixture of ice and industrial fish 2 m above deck level, discharging it into the funnel (8); (8) funnel and plastic tubes leading the mixture to the scuttle (9) on the deck; (9) one of a number of ice scuttles installed over the hold sections for industrial fish; and (10) discharge of food fish from the rotating grader (3).*

deck and releases it into a funnel. Wide plastic tubes connect the funnel to the ice scuttle in the deck over the section of the hold that is to be filled with iced industrial fish. Most of the ice melts within a few hours, leaving the fish chilled to 0°C. The water should be discarded immediately; so the hold should be equipped with adequate drainage.

The continuous supply of ice to the trough under the grader is taken from a store of bulk ice. In the bottom of the store, a horizontal conveyor feeds the ice onto a vertical conveyor to the trough. The conveyor speed is adjustable so that the supply of ice can be varied. At landing, there should be little or no surplus ice. A fish at 15°C when caught requires about 23% of its weight in ice to be chilled and maintained at 0°C for 4 days.

Food fish passing through the rotating grader are a mixture of many species and sizes, and the total amount varies considerably. Improved equipment and facilities are required if all these fish are to be handled, chilled, and stowed properly for food purposes. The larger fish are gutted by hand, washed, and iced either in bulk or in boxes. Because of the shortage of labour and facilities, bulking of mixed fish species prevails over boxing, but grading into species and boxing are preferred because the quality of the fish suffers in bulk stowage.

At present, trawler owners are planning to place one line of containers in the central gangway. The size of this gangway and of the hatches limits the base of the containers to 1 m^2. The height of the containers will probably be 2.25 m, and their capacity will be about 1 t of fish each.

The chilling system is that developed by the British White Fish Authority. The containers, which are heat-insulated, are charged with ice in port before being lined up on the floor of the fish hold. Just before the container is filled with fish, seawater is added up to the level of the ice, and the contents are mixed by the introduction of compressed air at the container bottom. This circulation is maintained while the container is being filled and until most of the ice has melted and the fish temperature brought below 0°C. The container is kept closed as long as the fish temperature remains near 0°C. Repeated chilling by brief air circulation may be required during extended storage. The fish are unloaded in the containers, which may serve briefly as raw-material storage for the filleting industries. They are emptied by a tilting device.

Laboratory and pilot-plant studies have shown that it is necessary to discard the belly flaps of fillets cut from whole whiting and haddock. Such fillets should not be sold fresh; they should be preserved — frozen, dried, canned, etc.

Strategies to Avoid By-Catch in Shrimp Trawling

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This paper briefly reviews strategies that have been used to reduce fish by-catch in commercial shrimp fisheries. Although substantial gear improvements have been made in recent years, by-catch — particularly in tropical fisheries — remains unacceptably high. One possibility is to deter the fish from entering the shrimp nets by appropriate stimuli that induce escape reactions in fish while leaving shrimp vulnerable to capture. To be effective, such stimuli must be applied at a point perhaps 1 minute ahead of the trawl. Sound seems to offer the best potential. The radius of influence of sound-induced stimuli is sufficiently large to warrant consideration, and sound frequencies sufficient to induce avoidance reactions in fish can be generated at energy requirements available in the power supply of most shrimp trawlers. The presentation concludes by briefly outlining a testing program sequence that could be carried out jointly by a number of agencies.

Most shrimp fisheries are in warm, tropical or subtropical, waters where capture systems have developed from fixed traps and weirs through various nets in the estuarine coastal zone to deep-sea specialized trawl gear. The total catch of shrimp exceeds 1×10^6 t/year. The fish captured with the shrimp varies from 5 to 10 times the weight of shrimp landed. With fixed devices and near-shore operations, small quantities of catch are involved; however, in motorized trawler fishing in deeper waters, the volume of fish and shrimp is generally great. The fish are stunned by the crush of the trawl and by the lessened pressure when brought to surface. They are separated from the valuable shrimp by hand on deck by the crew and generally discarded. Crew time and the consequent costs and serious wastes would be considerably reduced if gear landed only shrimp or at least reduced the quantity of incidental catch of fish. Fishing tactics and electronic detectors assist in aiming the trawl at the available shrimp, but these improvements have not avoided the by-catch.

Efforts have, therefore, been made during the past 30 years to redesign the standard otter trawl and to perfect a specialized shrimp trawl. The objective has been to achieve as "clean" a catch of large shrimp as is possible — that is, at an efficient rate of capture, with the minimum of other fish or organisms. However, the by-catch problem persists, particularly in tropical estuarine shrimp grounds. By-catch of fish in the shrimp trawls is generally about 85% by weight of the total catch, although it is occasionally as low as 40%.

Here, is considered only the option of reducing the fish/shrimp ratio in the catch by means of selective fishing methods. Specifically, this presentation will make a theoretical analysis of the benefit that might be achieved by separation of fish from shrimp on the fishing grounds by an application of appropriate stimuli ahead of the trawl.

Background

There is an extensive bibliography of selective-fishing methods and gears for shrimp fishing. Many improved trawl designs have been developed over the past 10–15 years. Nonetheless, the implementation of this technology by the industry has been slow and the fish/shrimp ratio in commercial catches remains high on average. Various designs and modifications are described in the literature on the Gulf of Mexico's shrimp trawls, balloon and midwater trawls, Gulf of St. Lawrence separator trawls, excluder trawls with escape chutes, beam trawls, and some electric trawls. The authors of the papers have indicated promising results and have supported their claims with data. However, the trawls have not been adopted for widespread use in tropical fisheries where the fish dominate the trawl catch.

With a further 2 years of concentrated effort, tests, and operations in different conditions, researchers indicate that an efficient, workable separator trawl can be perfected for the Gulf of Mexico conditions. Already, in Oregon, some fishing operations use an effective separator trawl, but its manufacture and special rigging may be too difficult for incorporation by traditional net makers. Vessel captains and net makers prefer their own particular design, and new designs are not readily accepted by them or by crews who must repair the trawls at sea and are biased in favour of standardized systems.

There are factors, however, that favour the acceptance of new trawling methods. Chief of these is the increasing cost of fuel that has placed at a premium the available frozen-storage space upon a trawler. The most valuable catch is the shrimp, and, thus, the savings in space and labour through the use of an efficient shrimp trawl are highly desirable for the industrialized and technologically advanced fisheries. The saving of the incidental catch alive is also highly desirable for resource conservation; better still would be to avoid catching the fish in the first place. Present techniques and equipment, especially the small mesh required to catch shrimp, harvest large numbers of immature fish. This fact limits the ability of the resource to renew itself.

When considering strategies to reduce by-catch in shrimp trawling, one must remember that the shrimp fisheries are highly diversified and, like all near-shore fisheries, are strongly adapted to local conditions and traditions. Thus, ideally, one would minimize changes in gear technology and undertake a preselection of the fish prior to harvesting.

Special emphasis has been given in protein-deficient countries to the use of the incidentally caught fish as food for humans. Such countries seek to use all the fish that are harvested and are not specifically interested in selective trawls. These circumstances commonly result in progressive expansion of the fleet, increased fishing pressure, and less-than-optimal resource management, which are matters of great concern. Accordingly, management options including fleet limitations, seasonal closures, gear-mesh regulations, and fishing zones are often advocated. However, like the collection and use of the by-catch, these procedures do not completely solve the by-catch–shrimp problem. Such management measures should, nevertheless, continue, perhaps with special incentives (for example, privileged zones of a fishery, to vessels with efficient, shrimp-only trawls).

Sorting of the by-catch landed on deck can be facilitated by mechanical sorters, but such sorters only assist in the recovery of food fish, not in their survival as a future food source for larger fish. In future, if large vessels collect all the catch, they will increase the fishing pressure on the resource base and may deplete stocks irrevocably. Accordingly, underwater separation of fish and shrimp to ensure survival of the juvenile fish found with the shrimp is clearly highly desirable.

Proposed Approach

A trawling model (Fig. 1) has an opening of 18 m × 2 m, warps 350 m, and bridle 65 m. At a trawling speed of 1–1.5 m/second, the trawl mouth will cover some 60 m × 40 m × 20 m every minute. The fish and shrimp that inhabit this zone are collected concurrently in the net because their escape responses are too late and too slow for them to move away from the trawl mouth. Escape velocities of fish, regardless of direction, reflect "burst speed" that, in fish 8–25 cm long, is in the order of 0.6–2.0 m/second. Sustainable swimming speed is considerably slower. However, if this area ahead of the trawl, which in the example is 48 000 m^3, can be flooded by stimuli that induce escape locomotion in fish, a high level of presorting can take place. Such stimuli would allow for escape at sustainable swimming speed rather than burst swimming speed. Such presorting would greatly facilitate the operation of mechanical sorting systems including escape chutes within the trawl itself.

Thus, if a stimulus that induces fish to move away were applied to a zone 1 minute ahead of the trawl mouth, separation of fish from shrimp would be in situ. This approach has apparently not been tried.

Constant or sustainable swimming speeds and burst speeds for clupeiform fish are, respectively, in the order of 3 body lengths/second and 10 body lengths/second, the latter of which can only be maintained for 10–20 seconds. Shrimp utilize a totally different method of locomotion, and those that are 8–12 cm long can maintain temporary bursts of approximately 0.2–1.0 m/second.

To achieve effective presorting ahead of the

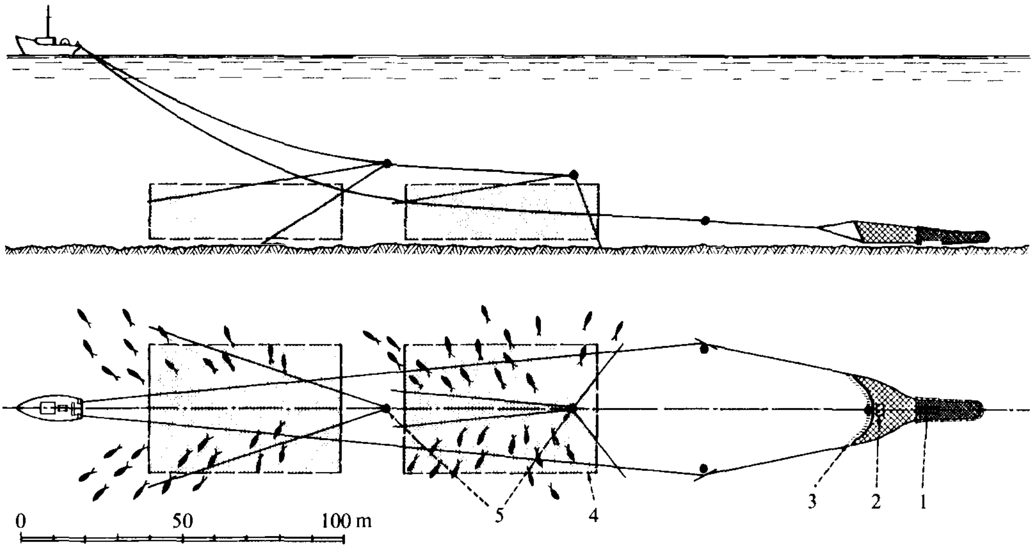

Fig. 1. *Model: boat — 18 m long, 150 hp, trawling speed 1–1.5 m/second; gear — semiballon trawl, opening 18 m × 2 m, warps 350 m, bridle 65 m; (1) cod end escape device; (2) baiting shut; (3) electrode array; (4) area affected by physical stimuli; and (5) possible sites for physical-stimuli generators.*

trawl, it will be necessary to apply one or more types of stimulus using equipment that can be operated from on board the fishing vessel with the power sources on the vessel. Various stimuli can be considered to induce trawl-avoidance reactions in fish at sustainable swimming speeds. These include sound, light, hydromechanics, and electricity.

The literature on locomotor responses of fish and shrimp to such stimuli is spotty, with reported responses being highly variable between species. Further, the most reported studies are on freshwater, temperate fish species, notably salmonids, and the data may not apply to fish in the tropics. Nonetheless, there are reports of differential responses between fish and shrimp species.

Illumination, above sensitivity thresholds 10^{-4} – 10^{-7} lux, is widely used in selective fisheries, but there is little indication that the sensitivities of fish and shrimp are so different that controlled illumination would be a practical basis for presorting, particularly as shrimp trawling is most successful at night. Nevertheless, differences in light-adaptation times between fish and shrimp might be exploitable for this purpose, particularly as the radius of influence is quite large. For example, an initial illumination of blue–green light from a 1-kW source directed at a 20° angle falls in the sensitivity threshold in the order of 10×10^{-5} lux/m^2 in water with an attenuation factor of 0.2 (moderately transparent) within a distance of 35 m.

Sound is a more promising tool than light. Fish have highly developed auditory and lateral-line responses. There is the potential, particularly by manipulation of the intensity and frequency of sound, to control the escape response of fish in a zone ahead of the trawl. The acoustic range of hearing in fish is in the order of 6–13 $\times$ 10^{-3} cycles/second, with sensitivity thresholds of 20–60 dB. Lateral-line response occurs throughout the range 15–300 $\times$ 10^{-3} cycles/second. In contrast, the sensitivity of shrimp to sound is very low and occurs only at low frequencies.

The chief attraction of sound as a potential source of escape stimulus is the large area that can be covered at only modest power requirements. For example, although absorption losses increase at high frequencies, even at the highest frequencies (in the order of 13 $\times$ 10^{-3} cycles/second), the rate of loss against distance is only about 0.5 dB/100 m.

The technology exists to design transducers for any desired sound frequency. Further, within limits, the direction of sound transmission can be controlled, and the problems of reverberation, scattering, and ambient noise are potentially controllable.

Fish show a strong, unconditioned response to all electric currents; direct current (DC) and positive-pulse electric current create both attraction and repulsion of fish, whereas alternating current (AC) and bipolar pulses repel. Response frequencies are 20–60 cycles/second. The response is of short duration and occurs at distances up to 3–4 m from the electrode. To exploit electrical response as a stimulus for presorting, one must control the location of the electrode arrays, the power supply, and the timing of the current hits.

The major problem with using electrical fields in seawater is energy loss. Seawater is an electrical resistor, R, that creates, during time, t, at a current, I, energy losses of I^2Rt. These losses would be reduced if modulated pulses of minimal energy per pulse unit were used to frighten the fish. An exponential-shaped pulse of perhaps 0.2 m/second could be effective. Diminished losses could also be achieved by the placing of electrode arrays throughout the desired area.

Even under optimal conditions, power requirements to cover an area of tens of metres would be many kilowatts. Experience has shown that pulse generators of 5 kW repel small fish over a volume of 100 m^3. Fish would be repelled at distances of approximately 4 m from each electrode of an array.

Thus, electrical fields could play a supporting role in presorting, by initiating fish response. Other supplementary applications of electrical fields may be within the trawl itself, specifically to enhance performance of the escape chutes.

There are many reports that describe responses of fish to environmental perturbations such as air bubbles, waves, and the like. Conceivably, such hydromechanical stimuli could play a role in presorting. Disturbances such as air-bubble screens can be readily induced, and, in the case of air bubbles, sound frequency and intensity can be modified by control of air pressure and nozzle design. Induced air bubbles produce sound in the range of 1000 cycles/second and repel fish at distances of 2–4 m from the stimulus, attracting them at longer distances.

Evaluation

Whether a novel shrimping system is useful primarily depends on its acceptance by shrimpers and its compatibility with the existing boats and gear. Presorting ahead of the trawl could meet the second criterion. None of the proposed methods are likely to have power requirements greater than the 10–15 kW available on a motorized shrimp boat and would have minimal effect on established gear and fishing tactics.

Of the stimuli examined, sound is the most promising. Because of the differences in sound response of fish and shrimp, a practical method of presorting ahead of the trawl should affect only the fish, leaving shrimp catches unaffected. The system could be used in combination with other proven technologies, including improved trawl design.

The concept of presorting needs evaluation. An evaluation program would have three phases:

- Phase 1 is a pragmatic study, the aim of which would be selection of a sound-producing system. It would include direct testing and visual assessment of the relative responses of fish and shrimp to sound stimuli. The work could be carried out either in the field — the observations being made by divers, sonar, or TV cameras — or in a test facility.
- Phase 2 — carried out if the first phase is successful — is to design equipment suitable for use by a shrimp trawler and to test it within a shrimp fishery.
- The final phase of testing would involve evaluation and local adaptation of the system to the various shrimp fisheries by means of commercial trials.

Several research laboratories, particularly in North America and Europe, have experience and expertise in this general area. Evaluation of the program would need joint effort by these laboratories for 2–3 years. Expenditures for the first and second phases of the program would be about $120 000 and $180 000, respectively, if governments provided the inputs of research vessels as their contribution to the program.

We believe there are merits in such a study and recommend governments support it as an applied research program with the collaboration of interested laboratories. Possible participants in the study from Canada are: B.C. Research, Techwest Limited, Nanaimo Biological Station (all Vancouver), and Technical University of Nova Scotia (Halifax); from the USA: Northwest Fisheries Center (Seattle), and Southwest Fisheries Center (Pascagoula); from the U.K.: Marine Laboratory (Aberdeen) and White Fish Authority (Yorkshire), and from the USSR: VNIRO (Moscow).

Handling and Storage of Shrimp By-Catch at Sea

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The vessel Marsep, a double-rigged shrimp trawler, was used in handling and storage trials at sea. In these trials, three voyages were made in the 1979–80 season, and storage trials were completed ashore after the voyages. Washing and icing by-catch at sea yields a demonstrably better quality than do other techniques of handling the by-catch at sea. The results in this paper are based on trials that may be representative of average operations of the fleet in this area.

Each year, approximately 1.2×10^5 t of fish are caught in the Gulf of California by trawlers based at the ports of Puerto Peñasco, Mazatlan, and Guaymas. In 1970–71, the Guaymas shrimp-fishing fleet comprised 282 vessels and had grown to 429 vessels by the 1978–79 season. Vessels continue to be recruited to the fleet at a yearly rate of 25–30 boats. The recent trend in the design of shrimp trawlers has been to produce large (22–24 m, 71–80 t) vessels fitted with sophisticated radar, communications systems, and depth-finding equipment. Approximately 35% of the Guaymas fleet (mostly the newer vessels) is equipped with fast-freezing and cold-storage facilities capable of handling 15–25 t of headed frozen shrimp during a single voyage. The cost of building and fitting out such a shrimp trawler ranges from U.S. $120 000 to $240 000. The duration of a voyage is 2–6 weeks, and the cost of a single 2-week voyage, calculated during the 1976–77 season, is about $2640.

Not surprisingly, the large well-equipped shrimp fleets operating from the Gulf ports have had a significant impact on the area's shrimp resources. In the 1970–71 season, when only 282 boats operated from Guaymas, the total shrimp catch was 3866.9 t. In the 1978–79 season, despite a 52% growth in the fishing fleet, the total had risen only to 4382.0 t — an increase of 13.3%. Moreover, the figures fell from 13.7 t/boat in the 1970–71 season to 10.2 t/boat in the 1978–79 season. The high export price, $8/kg, for shrimp landed at Guaymas in the 1978–79 season ensured a revenue of about $19.52 million, whereas total running costs for this fleet rose to $7 million. If the overall catch of shrimp continues to fall each season and the fleet continues to expand, the profit margin from shrimp sales will drastically decrease.

Shrimp-Fishing Methods

The vessels fishing in the Gulf are double-rigged shrimp trawlers, generally fishing at night for commercially valuable shrimp species of the genus *Penaeus* and using standard methods for trynet and twin trawls.

The crew (4–5 members) sorts the catch using rakes to separate the shrimp from the by-catch. The shrimp are headed and collected in baskets. At the end of the sorting operation, the by-catch is jettisoned to the sea. The headed shrimp are thoroughly washed, then either quick-frozen and cold stored, or stored in ice.

Data collected for nine consecutive trawls over 72 hours showed that the average trawling time is 4.39 hours. The average time taken to complete each step is: 8.2 minutes for landing the trawl; 10 minutes for resetting the trawl; 42.1 minutes for sorting catch and heading shrimp; 5.3 minutes for clearing the decks; and 13.3 minutes for shrimp washing and stowage. Between the completion of these deck operations and hauling the next trawl, there is a mean interval of 2.9 hours during which the deck is temporarily unused as the crew rests.

In nine consecutive shrimp trawls made over a 40-hour period, the average catch of shrimp per trawl was 23 kg, the mean catch rate of shrimp was 5.3 kg/hour, and that of by-catch was 59.5 kg/hour (Table 1). Although this rate agrees with that of 60 kg/hour calculated from 45 trawls during the 1977–78 season, the mean catch rate of

Table 1. Breakdown of time needed in shrimp-fishing operations (data collected for nine trawls).

Trawl re-setting (min)	Trawl (min)	Trawl landing (min)	Sorting (min)	Deck cleaning (min)	Washing, stowage of shrimp (min)	Crew	Shrimp (kg)	By-catch (kg)	By-catch/ shrimp	Shrimp (kg/ hour)	By-catch (kg/ hour)
14	240	7	35	5	16	4	18	200	11:1	4.5	50.0
8	230	6	75	8	14	4	45	200	4:1	11.7	52.2
9	522	14	65	3	13	5	45	275	6:1	5.2	31.6
10	200	6	35	1.5	12	4	10	150	15:1	3.0	45.0
7	223	8	25	5	13	4	10	250	25:1	2.7	67.4
11	225	7	30	6	13	5	6	300	50:1	1.6	80.0
10	225	8	30	6	12	5	12	250	21:1	3.2	67.0
9	245	10	46	8	15	5	36	300	8:1	8.8	73.5
12	260	8	38	5	12	5	30	300	10:1	6.9	69.2

shrimp in the latter study was much higher (10 kg/hour).

A careful observation of the fishing activity revealed that, above deck, space is not available for the permanent storage of items unessential to the fishing method — an important factor for considerations about the possibilities for above-deck storage of by-catch.

On-Board Handling

The plan for industrial use of the by-catch considered applicable to the Mexican fleet involves the initial separation of the finfish portion. It was found during trials at sea that the rate at which the crew could sort the finfish by hand from the by-catch depended upon the size and species of the fish caught. The average time of sorting determined from a number of trawls of differing species composition was 1 kg finfish/0.7 minutes/worker (Table 2). Thus, four workers could separate 2 t of by-catch in about 350 minutes, or, in more practical terms, if, during a 10-day voyage, the catch-handling time were extended by 10–15 minutes after each trawl, it would then be possible to sort and wash 2 t of by-catch.

The process of heading and gutting by-catch finfish was examined in an attempt to determine its effects upon the keeping quality of the fish. The rate at which the process could be carried out on board a commercially operating shrimp trawler was, once again, found to be dependent upon the size and species of fish present in the catch. Because the fish are generally small, gutting of the major part of the finfish portion could only be accomplished if the fish were cut in half. On average, the time taken to gut and wash the finfish for storage and preservation was 1 kg/ 4.7 minutes/worker (Table 2). This rate was derived from observations of workers unaccustomed to gutting and heading fish. Observations at the shore-based plant of Pro-

Table 2. Trawl and prestorage treatment (for Marsep voyage).

Trawl	Trawling time (min)	Trawl depth (m)	Temperature (°C) Water surface	Ambient air	Estimated weight (kg) Shrimp (whole)	By-catch	Sorting time (min)	Number of workers sorting	Time for 3 workers to: Sort 100 kg finfish from by-catch (min)	Head, gut, wash 30 kg finfish (min)
1	175	8–10	19.0	20.0	80	500	60	5	–	–
2	155	8–10	19.0	20.0	70	300	35	4	25	45
3	230	8–10	19.0	19.5	90	350	65	5	20	–
4	205	15	19.0	19.0	40	200	45	5	–	49
5	260	30	19.0	20.0	20	210	45	5	–	–
6	320	30	19.0	20.0	50	200	40	5	29	–
7	260	18	19.0	23.0	2	100	15	5	20	–
8	265	30	20.0	21.5	28	250	35	5	–	–
9	240	30	20.0	18.0	60	150	30	5	–	–
10	270	32–40	19.0	18.5	10	350	60	4	–	–

Table 3. Handling and storage of finfish sorted from the shrimp by-catch.

Treatment	Days stored	Visual appearance	Microbiological analysis (TVC on skin)	Torrymeter score
Gutted; washed; iced	8	Very good	3.1×10^6	13.9
	18	Good	–	9.6
Gutted; washed, stored at -8°C	8	Good	3.9×10^6	7.1
	18	Acceptable	–	6.3
Gutted; washed; quick-frozen; stored at -8°C	8	Good	3.5×10^6	8.4
	18	Acceptable	–	6.5
Gutted; iced	8	Usually good	3.0×10^6	13.0
	18	Good	–	10.9
Gutted; stored -8°C	8	Acceptable	1.3×10^7	7.4
	18	Unacceptable	–	–
Gutted; quick-frozen; stored at -8°C	8	Acceptable	2.2×10^6	4.3
	18	Unacceptable	–	4.0
Washed; iced	8	Very good	2.4×10^6	13.6
	18	Acceptable	–	11.3
Washed; stored at -8°C	8	Acceptable	3.7×10^7	6.9
	18	Unacceptable	–	4.1
Washed; quick-frozen; stored at -8°C	8	Acceptable	3.9×10^7	5.8
	18	Unacceptable	–	5.3
Iced	8	Very good	3.0×10^6	12.8
	18	Good	–	10.3
Stored at -8°C	8	Good	1.0×10^7	8.3
	18	Unacceptable	–	6.5
Quick-frozen; stored at -8°C	8	Acceptable	1.0×10^6	6.4
	18	Unacceptable	–	4.5

ductos Pesqueros Mexicanos (PPM) showed that trained workers could head and gut the by-catch fish much faster: 311 kg of finfish were headed and gutted by 11 workers in 1 hour, i.e., 1 kg fish/2.12 minutes/worker.

Preservation and Storage at Sea

Many of the modern shrimp trawlers are equipped with quick-freeze units, capable of freezing the catch from 20°C to -13°C in 30 minutes. The cold store operates at -8°C; there is also an insulated storage area that is some 2–3°C lower than the ambient temperature. The insulated storage area is suitable for stowing ice and, during the storage trials, was used to stow ice and ice/fish samples.

The effects of various prestorage and storage treatments were evaluated on board (Table 3). Gutting involved the removal of the head and internal organs; where applicable, the samples were washed with clean seawater. The finfish were treated with ice, in an ice/fish ratio of 1 : 1. The samples were stored in boxes in the insulated area adjacent to the cold store. When necessary, the boxes were topped up with ice during the storage period, and the quantity of extra ice used was noted. The quality of each of the samples was assessed by microbiological (total viable bacteria in skin and muscle), visual, and Torrymeter evaluations. Determinations were carried out after 8 and 18 days' storage (Table 3).

Because the correct storage conditions could not be maintained, the quality changes of the samples prepared during the first (November 1979) and third (May 1980) voyages could not be monitored. The only relevant results were obtained from the second voyage in which all samples were stored in ice at least within 36 hours.

The study was undertaken jointly by the Overseas Development Administration technical cooperation team and the Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM). The Centro de Educación en Ciencias y Tecnologías del Mar (CECITEM), Guaymas, provided the vessel.

Processing on Shore

The Guyana Project: Industrial Use of By-Catch

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Industrial production of processed by-catch is the aim of a project in Guyana; it incorporates the facilities to produce individually quick-frozen fillets from seatrout and similar species; frozen fillets in blocks from croaker and other fish; fish patties and sausages from backbones, belly flaps, and nonconditional fillets; dried, smoked, and canned fish from bangamary and similar fish; and fish meal and oil from the offal. All these products have a local market, and many will serve an international demand. The plant capacity and the processing steps have been detailed here.

Shrimp have for many years been an important Guyanese fishery, equaling, in recent years, about 4000 t/year. As in other tropical waters, large amounts of fish are caught with the shrimp, and the practice until recently has been to discard the fish by-catch at sea.

The government of Guyana focused attention on the prevention of this enormous waste and decreed that the shrimp trawlers would bring part of the by-catch (1000 t/year) ashore, utilizing the freezing and storage capacity not occupied by shrimp. This directive resulted in fish landings that were used by Guyana Fisheries Ltd to pioneer a number of products, such as frozen fillets, fish paste, patties, and smoked fish — products that have found wide acceptance among local consumers.

The people of Guyana are accustomed to eating fish regularly, and about 50% of the protein consumption is marine or freshwater species. To enlarge the marine-protein supply, the government aims to intensify the landing of shrimp by-catch. In fact, it has initiated a program to acquire and rebuild a number of trawlers for finfish supply to the market. This program also includes a project to establish onshore facilities for processing raw fish (about 50 t/day) — 20 t for human consumption and 30 t for fish meal.

Plant Capacity

When planning the project, the authorities took the view that the products should be identifiable and directly acceptable to the population and that no investments would be made in equipment for manufacture of products that needed an extended introduction with an uncertain result. Furthermore, the government opted for a high degree of flexibility in the project, making it possible to reach all regions of Guyana, as well as other Caribbean countries, with fishery products.

A pilot plant is being tested, incorporating production capacities that have been chosen for their viability and feasibility so that increasing the scale of production constitutes no problems.

In brief, the project comprises:

- An ice plant to provide the necessary ice for raw-material storage in the trawlers and in the plant as well as preservation of processed material during distribution to the major population centres;
- A pretreatment line for inspection, deicing, washing, and sorting of the fish;
- Scaling, gutting, filleting, and freezing facilities, for production of individually quick-frozen (IQF) and block fillets;
- A process to produce fish patties and sausages from minced fish, surplus fish, belly flaps, and nonconditional fillets;
- A special line to prepare materials to be smoked, dried, and canned;
- Two drying cabinets for batch processing of salted, dried fish;
- A kiln for processing of salted, smoked fish;
- A small pilot canning line to develop products to suit consumer preferences (expressed in surveys); and
- An integral operation to process offal and discarded fish into fish meal as a basis for the growing poultry industry in the country.

The project was outlined by Guyana

Fisheries Ltd, who had, on a small or medium scale, manufactured most of the items described and had tested them in the market. The first part of the project was funded by the Commission of the European Communities through the European Development Fund and elaborated by Fisheries Development Ltd, London, England, in association with C.A. Liburd and Associates, Georgetown, Guyana.

An international call for tenders was arranged and the contract awarded to A/S Atlas, Denmark. Atlas then arranged cofinancing with Danish sources, thereby almost tripling the funds available and making possible essential additions to the project, such as an ice plant, canning line, fish-meal plant, etc. The arrival of equipment in Georgetown commenced in September 1981, erection to be under the supervision of personnel from Atlas in cooperation with local staff, especially on matters such as processes and mechanical and electrical details.

The plant is geared to process 200–400-g fish, with yields ranging from 30% of weight for skinless fillets to 85% for gutted fish. Yields of mince and fish meal from the offal are 50% and 20% respectively. Gutting and filleting are done by hand (5 fish/minute and 2 fish/minute). Mechanical capacities are heading 40 fish/minute, filleting 150 fish/minute, patty forming 350 kg/hour, sausage cooking 125 kg/hour, drying 100 kg/hour, smoking 100 kg/hour, and canning 30 kg/hour. Figures for weight of fish, yields, capacities, etc. will vary widely, depending primarily on sizes and varieties of raw fish, which will deviate according to source, seasons, etc.

Material Flow

Although the design of the operation (Fig. 1) assigns certain species for particular purposes, the plant is flexible so that several species can actually be used for each purpose.

Receiving and sorting raw material

The delivery comprises 2400 fish boxes, each with a volume of 40 L; the boxes fit telescopically into each other but are stackable when turned 180° horizontally. The material is polyethylene. After being emptied, the boxes are cleaned in a continuous box-washing machine with hot water and detergent.

This stage incorporates an Atlas scale ice-making machine with a capacity of 20 t/24 hours. The machine consists of two vertical, rotating drums, internally cooled by direct expansion of freon 22. Water is sprayed on the surface and freezes to ice during the rotation. In the final part of the freezing, the ice is subcooled to a temperature of -6°C, which makes it shrink and drop off at the touch of a series of knives. The compressor plant and drums form a unit with all switches and controls assembled in one control panel. An ice silo is planned as well; it will include three more machines of the same type on top, bringing total ice capacity to 80 t/24 hours.

When the raw fish are unloaded at the factory, they are immediately inspected, and any material unfit for human consumption is sent to the fish-meal plant. Some of the material may be reiced and placed in chilled storage (0°C), whereas part of the catch is selected to be processed immediately. The latter is washed and deiced in a machine consisting of a vat filled with clean, running water, through which an inclined, continuous conveyor moves fish out of the vat and allows them to drain. In a subsequent operation, the fish are sorted according to species and size, the sorting line consisting of six working places and of conveyors for raw fish and for discarded fish. Fresh fish, destined for direct sale, are repacked in ice and placed in the chill storage, awaiting distribution. Further processing depends on the quality of the fish and their suitability for specific products.

IQF fillets

Seatrout (*Cynoscion virescens*) and similar species entering the line pass through a Canadian-made machine that removes the scales. This operation is performed by rotating cutters of flat and conical design, the fish being held by spring-loaded, curved, pressure plates. An internal spray of water flushes the scales out of the machine. Afterward, the fish are gutted by hand and washed in a stainless steel, perforated drum, furnished with internal water-spray nozzles and placed on an incline.

The washed fish are dumped into fish boxes and weighed on a platform scale for control of the filleting yield. The main filleting line consists of 12 working stations with cutting boards of hard nylon. There are three conveyors placed on top of each other, one for fillets, one for boxes with gutted fish, and one

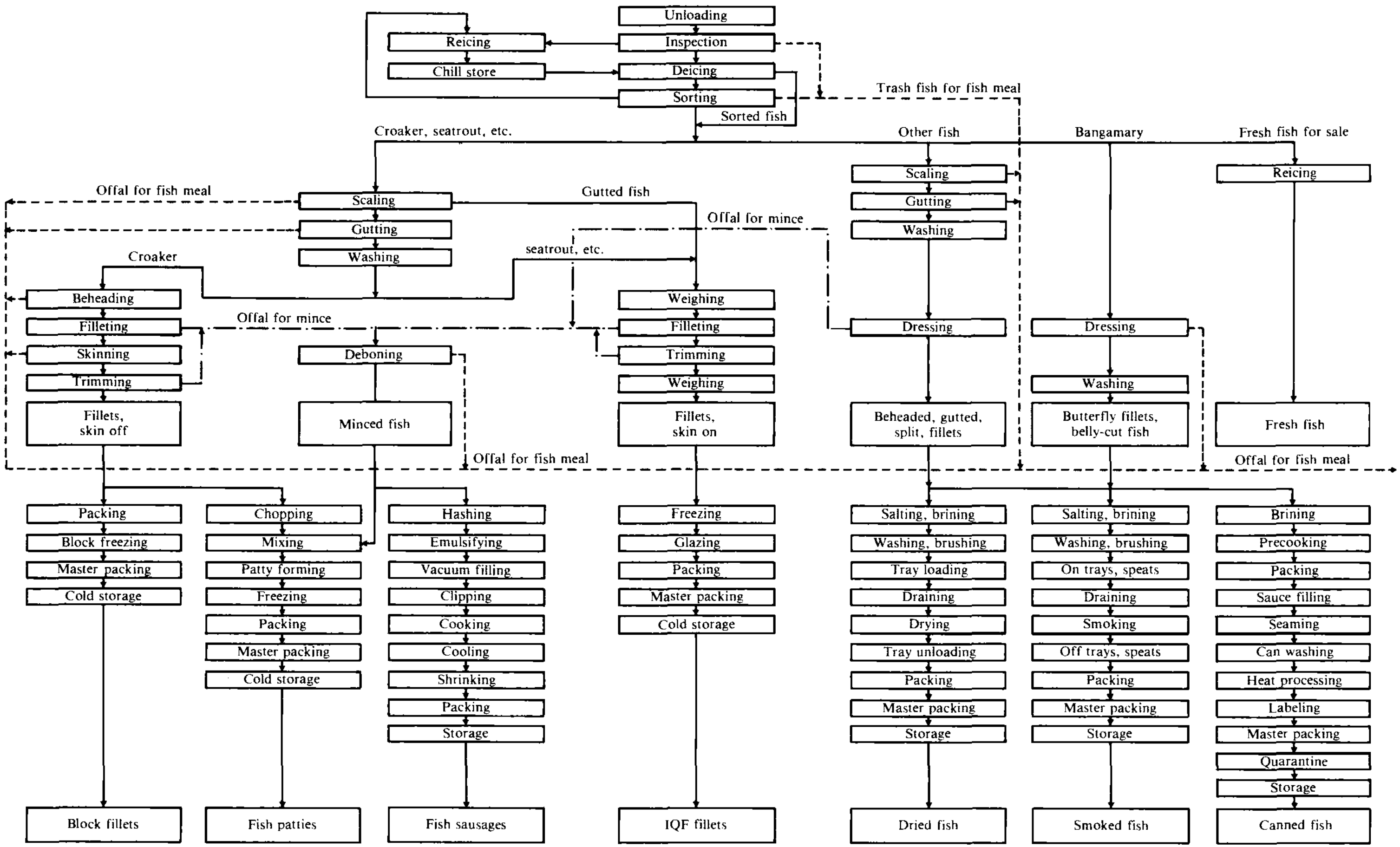

Fig. 1. *Products and processes for the Guyana plant.*

for offal. The fillets are inspected on a special table and weighed; then they are ready for freezing. Trimmings and backbones are collected for production of fish mince in a flesh-and-bone separator.

The freezing is performed on an Atlas Rotafreeze IQF in-line system. The fillets are placed on a conveyor with wire mesh in stainless steel. The freezer itself is a large stainless-steel drum, internally cooled by a transfer liquid, which in return is cooled by a two-stage piston compressor system.

The freezing drum rotates slowly, and the fillets from the freezing conveyor are placed automatically on the drum, maximum contact being secured by a soft-pressure roller. At the end of the rotation, the frozen fillets are detached from the drum by means of a special device, and they drop onto a take-away conveyor. This conveyor transfers the fillets to the glazing unit from which they continue on a band conveyor to a portion-packing station with five tables, each furnished with scales. The prepacked products are weighed and placed in master cartons, which are labeled and strapped, ready for cold storage and dispatch.

Frozen fillets in blocks

Croaker (*Micropogon* spp.) and other fish of similar size and structure are to be filleted and frozen in blocks. Equipment already present in the plant includes a filleting machine from Japan and surplus freezers used for production of frozen shrimp. However, for flexibility, two lines — each with eight working stations — have been included. These lines — the same design as for IQF fillets — have three conveyors and will take care of fish not suitable for mechanical filleting and will operate even during breakdowns in the filleting lines. Also, the two lines may be used separately, for instance for packing of fillets in cartons before plate freezing.

The final arrangement of the machinery will be decided on the basis of experience, but care has been taken to provide for the elements necessary to obtain a smooth and flexible operation.

Fish patties and fish sausages

Quite a lot of importance has been attached to the production of patties, pâtés, and sausages, as these items have been produced on a small scale for some time with a good response from consumers. The raw material is backbones, belly flaps, and nonconditional fillets, which will be deboned in a Bibun flesh-and-bone separator into fish mince and offal for fish meal. The installation also permits the elaboration of methods for the manufacture of mince from small fish, with and without heading and gutting. Using the whole fish is a distinct possibility, as the colour of the mince as well as presence of black spots is much less critical in pâtés and sausages than it is for surimi, fish blocks, or fish sticks. The patties, pâtés, and sausages will be spiced and artificially coloured to suit consumer preferences in the various regions of the country. Smoke flavour can be added by the smoking plant.

The minced fish are transferred to a chopper–mixer machine, principally consisting of a cylindrical, vertical container, which has two sets of combined mixers and knives built into the bottom. By varying the speed of the rotating knives or removing them and keeping only the mixing device, one can adjust the consistency within wide limits: the mixture for sausages and pâtés will be rather smooth, whereas patties are expected to contain bits of fillet to be chewed.

During the mixing, scale ice is normally added to keep the temperature down, together with spices, colouring, preservatives, and antioxydant (when fatty fish are used).

In patty production, the mix proceeds to a patty-forming machine consisting of a hopper with feed screw, a pressure chamber that ensures constant filling of the pistons, and a forming set, in which the round patties are shaped to a finely adjusted weight. When the moulds of the forming set are filled, the forming plate moves forward to the release position, the patties being expelled onto an outfeed conveyor. They are then frozen on the Rota-freeze and packed as for IQF fillets.

The mixture of fine mince, destined for sausages proceeds to a vacuum-filling machine for casings, and the sausages are portioned and clipped according to the desired weight. The clipped sausages are then pasteurized in a cooking vat for about 1 hour, the centres reaching a temperature of about 90°C, whereafter they are cooled in cold water. Perfect shrinking of the casing is ensured by a final dip in hot water for about 10–30 seconds, and the sausages are ready for packing and storage.

Dried, smoked, and canned fish

The raw material for dried, smoked, and canned fish will be bangamary (*Macrodon* spp.) and fish of similar shape and size. Filleting machines, of the type successfully developed for handling herring and blue whiting in the north Atlantic region, will be tested in this operation because they can deliver single or block fillets, skin on or off. If the filleting tests are not successful, dressing of the fish can be undertaken on the filleting line.

The fish destined for drying will be split or filleted, skin on, then salted lightly (brined) or heavily. As brining is also the initial process in smoking and often also in canning, the plant has been furnished with an automatic brining unit. This unit consists of a main tank, furnished with paddles that convey the fish through the brine at an adjustable speed. A saturated sodium chloride solution is kept in a tank and is added in measured amounts to the main system so that the concentration of salt in the brine is constant. A pump circulates the brine from the main tank through a buffer tank with filter in which solid particles are settled and can be drained.

It is normal to use a brine of about 210 g NaCl/L and an immersion time of 1–5 minutes, depending on size, thickness, and oil content of the material. This treatment gives a salt content of about 3% in the fish, which, after being dried to 15–17% moisture content, will have about 8–11% salt content.

To produce heavily salted fish, one places alternate layers of material and salt in containers, possibly keeping the brine in the container until the fish have obtained the desired amount of salt. Whereas lightly salted fish must be dried to a moisture content of less than 15% to prevent growth of bacteria and moulds, a moisture content of 35–40% is suitable for heavily salted products. Also, the drying time for heavily salted fish is shorter than that for lightly salted fish, and, thus, the output of the dryers will be considerably higher for heavily salted fish.

After being salted, the fish are washed so that crystals don't form on the surface; they are then placed on wire-mesh trays in the trolleys of the drying cabinets. Two dryers (Afos, England) have been supplied to the project, each one accommodating four trolleys with about 20 trays each. Each batch per dryer will be about 1270 kg (based on medium-sized cod fillets).

The dryers consist of cabinets with four doors for passage of the trolleys, which are stationary during the drying. On the top and sides of the cabinet, there are air ducts furnished with aerofoils and diffuser walls for even distribution of the air current throughout the cabinet. The air flow is provided by a fan placed in the upper duct. In the same duct is also placed a thermostatically controlled air heater. The bulk of the air is recycled, but the humidity is controlled by an exchange between fresh and moisture-laden air.

The air velocity is about 1–2 m/second, and, according to experiences from other tropical countries, the air is about 40°C or even higher at the end of the drying. In temperate countries, it is normal to work with lower temperatures. The relative humidity should be 45–55%, as a lower value may cause a crust to form on the surface of the drying material and a higher value will reduce the drying rate. The finished products are discharged from the trays, inspected, and packed in portions, whereafter they are master packed, strapped, and labeled, ready for distribution.

Smoked fish

There are two types of smoking in general use, namely cold and hot smoking. In cold smoking, the temperature of the fish is kept low, so that coagulation of the proteins is avoided; in hot smoking, the fish flesh attains temperatures of 60–80°C, and the proteins are practically fully coagulated.

Cold smoking results in relatively little drying of the fish as well as in only a minor reduction of the bacterial count. Therefore, the products must be distributed with great care. Hot smoking can be carried out so that a higher drying rate is obtained, and the high temperature lowers the bacteria count.

In both cases, brining is done before smoking, the fish being dipped into a 75% saturated brine for 5–15 minutes — the amount of time depending on the thickness of the fish. When hot smoked and properly dried, the fish have a long shelf life. Therefore, hot smoking should be the preferred method in tropical countries.

Hot smoking is usually divided into three stages — a preliminary drying period (30°C) during which the skin is toughened against breakage, a smoking and partial cooking period (50°C), and a final cooking period (80°C). The total time and the proportion spent on each stage depend on the fish species, size, and fat content; the kind of products re-

Early experience in Guyana showed the wisdom of smoking by-catch fish.

quired; the final moisture content; and degree of smoking.

The smoking kiln for the Guyana project has only two trolleys and a batch capacity of 400 kg (based on white-fleshed fish fillets). However, as the ambient temperature and humidity in Guyana are often too high for safe operation of the initial process to toughen the skin, a dehumidifying system has been foreseen in the inlet for primary air. The dehumidifier is designed as a refrigerating system, with an air cooler having a capacity of about 30 000 kcal/hour at -1.1/54.5°C.

The smoking kiln (Afos, England) is

furnished with a smoke producer in which smoke is generated under controlled conditions. Sawdust from resin-free wood is poured into a hopper, and a feed screw with adjustable speed conveys it to a perforated grate, where it is electrically ignited and burned with a measured amount of air supplied by an adjustable fan. A rake pushes the burning sawdust forward on the grate until it falls as ash into the ashpit. After being smoked, the fish must be allowed to cool at least to room temperature, whereafter they are packed and kept in chilled storage until dispatch.

Canned fish

The possibilities for variation of canned products are legion. This fact is reflected in the canning plant to the extent that the design and capacity have been chosen as a pilot plant plus, which has a capacity high enough to test consumer preference without too much involvement in sophisticated equipment. Extensions can be made safely.

The raw material is placed on a buffer table and taken by a conveyor to the upper section of a packing table. This table is a circular rotating machine with three levels, of which the upper one is sectioned for raw material and empty cans, the middle one for filled cans, and the bottom one for offal. Five working stations are connected with the packing table.

The filled cans proceed on a conveyor to a saucing station in which they are filled with a measured amount of tomato sauce, brine, or oil; lids are added by hand, and closing takes place in a semiautomatic double seamer with a capacity of about 1500, 0.45-kg cans/hour. The cans are washed in a continuous washing machine and are dumped into crates for sterilization.

An autoclave, a water-filled, overpressure type, sterilizes the cans in a water bath at 115–120°C. Afterward, the hot water is pressed into an upper tank by cooled water entering from below. The hot water is reused for the start of the next batch.

The cooled cans are extracted from the autoclave, emptied from the crates, labeled, and packed; after a quarantine and inspection for swells, they are ready for distribution.

Fish meal and oil

Sorting of the raw fish as well as other operations produces considerable amounts of offal, which, together with the part of bycatch not suitable for human consumption, is used in fish-meal production.

The raw material is collected in carts and dumped into the feed hopper of the fish-meal plant. Backbones, sharks, rays, and other large items are cut into finger-sized pieces in a rotary knife-hasher. An adjustable screw conveyor feeds the material into an indirect cooker, which is a steam-heated, horizontal cylinder with a transport screw. The exit temperature is automatically controlled. The cooked material falls into a press with two counterrotating screws having conical shafts. The pressed cake is dropped into a Rotadisc dryer — a horizontal cylinder with an internal heating element consisting of a steam-heated shaft furnished with a number of hollow, steam-heated discs that provide a large surface for heat transfer. The dried meal is extracted from the dryer by a screw conveyor that transports it to a hammer mill after which it is bagged, ready for dispatch.

The liquid expressed from the cakes is pumped to a vibrator sieve in which sludge particles are removed and returned to the pressed cake. The oil is separated from the water in a centrifuge. The water is pumped to a tank, and, having a dry-matter content of only 8–10%, it is concentrated to about 45% in a two-stage, concentrating unit. The results are subsequently mixed with the pressed cake before it enters the dryer. This material increases the yield of fish meal by about 20%.

The plant is equipped with a wash tower for condensing the vapour in the dryer exhaust. Noncondensable gases can be used as primary air in the burner of the boiler plant so that obnoxious odours are removed.

The fish-meal plant will be erected close to a sawmill; therefore, the boiler plant has been designed to burn logs, shavings, and other offal from the sawmill. An auxiliary oil burner secures the operation of the boiler during periods of standstill at the sawmill. The main elements of the plant are supplied as preerected units with pipes, control panels, electric wiring, etc. ready for hookup. The cooker, press, dryer, strainer form one unit; the tanks, pumps, oil separator a second; the two-stage evaporator a third; and the boiler plant a fourth.

Conclusion

Having read this far, one may ask how the setup will accommodate new developments such as fish-protein concentrate (FPC), hydrolysates, silages, etc. The answer is simple: it won't. This project is based on the philosophy that the primary factors in elaborating a project are the raw materials and the markets. These will decide the products to be manufactured, and the products will determine the equipment, budgets, and economy, whereafter financing, cash flows, etc. will have to be taken into consideration.

This project is a pilot project plus — i.e., with regard to capacity, it is on the upper side of what is normally considered a pilot project. With the great flexibility built into the plant — its ability to transform a multitude of fish species into products already acceptable to consumers, in quantities that permit genuine cost and marketing experience — there is a fair hope that the venture will contribute to solving the by-catch problem.

Effects of Acetic-Acid Aided Evisceration on Deboned Minces from By-Catch Fish

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We studied gutting and cleaning methods that might be conducted efficiently and rapidly at a minimum cost. Five fish species that are frequently found in the by-catch were used. They were cleaned semiautomatically with 4% aqueous acetic acid as the active agent (AE — acetic-acid aided evisceration). We deboned the material, using a Paoli deboner and then analyzed the minces, comparing the findings with those for deboned minces prepared from manually gutted and cleaned fish (ME). We were able to process larger quantities of by-catch fish in shorter intervals with the AE method than with the ME method, and recoveries of deboned minces were similar (60%). The proximate composition of deboned minces was generally unaffected by the method of gutting and cleaning, although the extractability of nitrogen and the water-holding capacity tended to decrease in minces prepared from AE fish. Besides the colour of minces, few differences existed between the individual fish species. The use of the AE method with by-catch fish may radically improve the economic potential of this underutilized resource, without adversely affecting the quality of the deboned minces.

By-catch from the Gulf of California is a complex mixture of marine organisms, and the finfish portion comprises many small demersal fish species. Although it has been shown that it is possible to prepare by-catch fish manually on a factory scale in Mexico, labour requirements are extensive. Further, even though deboned minces from whole fish have successfully been used in dried, salted fish cakes (Young 1978b), the minces obtained are generally poor quality. The disruption of fish tissues and the intimate mixing that occurs during deboning can allow undesirable chemical changes to proceed more rapidly (Lee and Toledo 1977; Raccach and Baker 1978). These changes are further promoted if the deboned material contains the viscera of fish, and they result in dark minces that can have a high bacterial load. These factors may severely limit the utilization of minces prepared from whole fish.

Prototype machines capable of efficiently gutting small fish have been proposed for commercial processing, but they are designed for regularly shaped fish that are at least 20 cm long (Mendelsohn and Callan 1981). Thus, we studied a method of gutting and cleaning by-catch fish species in an attempt to reduce labour costs and time. The method consists of cutting the fish and soaking them in an acid medium.

Materials and Methods

By-catch fish were obtained fresh from commercial trawlers in the Gulf of California during the latter half of the 1980–81 season. The five species groups, which are frequently found in the by-catch (Young and Romero 1979), were mojarras (*Eucinostomus* spp.), orangemouth corvina (*Cynoscion xanthulus*), Gulf croaker (*Micropogon altipinnis*), bronzestriped grunt (*Orthopristis reddingi*), and cabaicuchos (*Diplectrum* spp.). Their average length is 12–17 cm and their weight 38–57 g. Analar grade acetic acid was used in the study.

Quantities of the fresh by-catch (60 kg/species) were divided into two equal lots, one to be cleaned by hand (ME) and the other to be cleaned with acetic acid solution (AE). The manual process involved cutting the fish heads off and slitting open the belly cavity so that the viscera could be removed. The carcasses were then cleaned, the black peritoneum and kidney tissues being removed when scrubbed by hand in ice-cooled water. Fish to be cleaned with acetic-acid solution were knobbed with a sharp knife. Carcasses were then chopped laterally into

Table 1. Basic analytical data for deboned minces (Gulf croaker, bronzestriped grunt, orangemouth corvina, cabaicuchos, and mojarras[a]), eviscerated manually (ME) and with the aid of acetic acid (AE).

	Gulf croaker		Bronzestriped grunt		Orangemouth corvina		Cabaicuchos		Mojarras
	ME	AE	ME	AE	ME	AE	ME	AE	AE
Gutted, cleaned fish (as % of whole fish)	58.4	51.9	53.3	57.7	68.0	64.7	63.8	54.4	60.7
Deboned mince (as % of whole fish)	36.0	33.6	33.5	43.3	45.8	41.9	32.1	26.8	37.8
Deboned mince (as % of gutted fish)	61.6	64.5	63.1	75.0	67.4	64.8	51.1	49.3	62.1
Total crude protein (N × 6.25) (%)	16.30	15.69	17.06	17.41	17.81	17.43	17.93	15.77	16.37
Moisture (%)	80.63	81.46	78.77	78.78	77.96	79.22	78.30	79.82	79.31
Lipid (%)	1.50	1.85	2.75	2.95	2.72	1.34	2.75	1.24	2.35
Ash (%)	0.93	0.73	1.19	0.81	0.99	0.78	1.25	0.80	0.90
pH	6.5	5.4	6.4	5.5	6.5	5.3	6.8	6.6	5.0
Total nitrogen (%)	2.61	2.51	2.73	2.79	2.85	2.79	2.87	2.52	2.62
N extracted by water (%)	30.30	25.24	27.73	22.62	24.89	22.83	31.73	27.60	21.31
N extracted by 5% NaCl (%)	58.15	37.02	40.78	39.88	43.86	45.85	36.45	41.27	28.99
N extracted by 10% TCA (%)	4.60	5.20	5.11	4.99	3.87	4.90	4.36	2.55	4.75
Drip (% — v/w — liquid lost on thawing)	0.1	9.2	0.8	4.0	0.1	9.8	0.1	0.2	2.0
TEF[b] (% — v/w — liquid lost on centrifugation)	29.8	48.0	43.4	39.8	28.8	45.4	28.8	37.6	39.2
Total weight, bones and scales (% dry-weight basis)	0.38	0.24	1.14	0.63	0.37	0.00	0.50	0.56	0.07

[a]Mojarras were not prepared manually because of their small size: average weight 38 g; average length 12 cm.
[b]TEF is total expressible fluid.

roughly 3-cm pieces and added to a 4% (v/v) aqueous solution of acetic acid (fish/solution, 1 : 1) in a plastic container. The mixture was stirred continuously for about 1 hour at ambient temperature (27°–33°C), strained and rinsed in two separate volumes of ice-cooled water. Both manually and acid-cleaned fish were then minced coarsely (Paoli mincer, model 863) and deboned by a Paoli deboning system (model 19-529). Deboned minces were frozen after being packed in polyethylene bags and stored at -20°C prior to analysis.

The deboned minces were analyzed for total crude protein (N × 6.25), lipid, moisture, and ash contents. All analyses were carried out in duplicate. Nitrogen extracted from deboned fish minces in water and in 5% sodium chloride was also determined. The solutions contained sodium bicarbonate (0.02 M) to maintain the pH at 6.5–7.0 during the homogenization. Samples were homogenized and then centrifuged (3500 g, 30 minutes) and the supernatants analyzed for their nitrogen content. The non-protein nitrogen (NPN) content of minces was determined in a similar manner, although ice-cold 10% trichloroacetic acid was used as the extractant and the bicarbonate was omitted.

We measured the pH of 2 g of mince homogenized in 10 ml of neutralized sodium iodoacetate solution (0.005 M) and determined water-holding capacity (WHC) of the minces following the method described by Tableros and Young (1981), giving values for free liquid lost from frozen minces after 3 hours of thawing and total liquid lost from thawed minces after centrifugation.

Bone and scale contents of minces were also determined, 10 g of fresh mince being dried to constant weight and then ground in a mortar. The mince disintegrated to a fine powder, and the residue consisted of the more durable bones and scales. These were counted and weighed and their combined weights expressed as a percentage of the dried weights of the minces.

Results

The use of an acetic-acid solution greatly reduced (more than 50%) the time required for gutting and cleaning. During the period that the chopped fish pieces were in the acid baths, the viscera of the fish disintegrated and dissolved to a large extent. The black peritoneum lining the body cavity became detached and the skin and scales could be rubbed off easily. This cleaning action may be caused by increased activity of the proteolytic enzymes endogenously present in the alimentary tract and on the skin.

Recoveries on gutting, cleaning, and deboning varied considerably for the fish species studied, regardless of the method of preparation (Table 1). This variation was ± 30% of the species mean calculated for deboned minces from whole fish and ± 20% for deboned minces from gutted and cleaned fish. The means obtained for deboned minces from fish prepared manually or by the use of acetic acid were similar.

The total crude-protein values of manually prepared fish were slightly higher than those of fish prepared with acetic acid, whereas the moisture values were a little lower (Table 1). The lipid contents of the deboned minces from the five fish species were all less than 3%. The ash contents of the minces were consistently reduced (20–30%) by the use of the AE method, and, as was expected, the pH levels of AE-deboned minces were lower than those of fish prepared manually (pH 5.4 and 6.5, respectively).

Larger amounts of nitrogen were extracted with 5% NaCl solution than with water (Table 1). There was no significant trend in the individual values obtained for ME and AE fish, although the mean values tended to be lower for AE-prepared minces. Similarly, there was no consistent trend for the nitrogen extracted by 10% TCA.

The water-holding capacity of minces when thawed was considerably reduced in those minces that had been prepared by the AE method, as indicated by the higher values for liquid lost during both thawing and centrifugation. The AE-prepared minces tended to have a lower bone/scale content because of a reduction in the number of scales (Table 1).

The colour of the deboned minces was subjectively determined and varied greatly between species: bronzestriped grunt and mojarra minces were extremely gray, whereas the other minces were white to cream. The AE method produced lighter-coloured minces from bronzestriped grunt than did manual evisceration, but no differences in inherently light-coloured minces were discernible.

Conclusions

The quality of deboned minces from fish gutted and cleaned either manually or with the aid of acetic acid was similar, although there were interspecies differences, especially with regard to their colour. The acid-aided method of evisceration considerably reduced the time and effort required and had the added advantage of lightening the dark minces. The water-holding capacity of the minces was reduced by the AE method, and this may affect their potential uses in the unprocessed form.

We are indebted to the Director and staff of the school of marine and food sciences of the Monterrey institute of technology (ITESM) for providing the facilities for this study and to Alma Rosa Rivas E. and Jorge Ramirez F. for technical help.

Salting of Minced Fish

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Cod myosin can be denatured by salt concentrations of about 10%. It should be possible, therefore, to salt minced fish with less than the 25% salt previously recommended. Preliminary results show that less brine is released from lightly salted mince but that the physical and functional properties of the product are related to salt concentration.

Seafood laboratories throughout the world have been investigating the potential of minced fish to increase the supply of edible fish protein and to provide the means for utilizing shrimp by-catch and other non-traditional species of fish. Several international conferences have been held on the subject, and there has been general agreement that one of the major problems with the utilization of minced fish is the development of acceptable and marketable consumer products.

Recent work at Halifax has focused on the salting of minced fish, as Canada has traditionally been a major producer of salted fish and the product currently has a strong international market demand. Results of our earlier work were incorporated in a collaborative project of the government of Guyana and IDRC as the basis for production of salted, minced fish.

Many will recall the original studies done by Del Valle and co-workers. Del Valle and Nickerson (1968) published a quick-salting process for fish that entailed:

- Grinding fish muscle with salt;
- Mixing the salt–fish mixture;
- Pressing the product at 2000 lb/in^2 (~140 kg/cm^2) to remove water and form cakes; and
- Drying the cakes to give a stable product.

In a subsequent paper, Del Valle and Gonzalez-Inigo (1968) applied the process to various species of fish and reported: "... adding amounts of salt lower than the required minimum resulted in gelatinous muscle masses which could not be pressed, while adding amounts of salt higher than the minimum resulted in brittle cakes after pressing." Mendelsohn (1974) of the Gloucester Laboratory in the U.S. proposed another process where skinless fillets were ground and mixed with saturated brine (1 : 1) to which sufficient extra salt (25 g/100 g fish) was added to saturate the tissue. The Halifax process used in the IDRC–Guyana project (Wojtowicz et al. 1977) requires the mixing, at 35°C, of minced fish with sufficient salt (salt/fish, 1 : 3) to saturate the tissue. This denatures the protein and gives maximum water release in a subsequent dewatering step that is followed by drying to about 22% moisture content. The product is stable at ambient temperatures. This process has many desirable features:

- Salting is rapid compared with the 2–3 weeks required for traditional salting;
- Mincing not only increases the rate of salt penetration but also facilitates drying;
- The product resembles traditional salt cod in chemical composition, odour, and taste; and
- The product has excellent shelf life.

The main disadvantages of the process are that the product is heavily salted, the protein lacks functionality, and the fibrous nature of the material is unattractive to some consumers.

The study that we relate here is still in progress and is aimed at resolving some of the disadvantages of the process. In essence, we wanted to produce a lightly salted, minced fish that would retain some of the functional properties of the protein and, accordingly, would be amenable to being formed into a cake or other shape.

The scientific basis for the study was a paper by Duerr and Dyer (1952), which reported: "... study of the denaturation of cod muscle proteins by sodium chloride shows that the myosin fraction is denatured when a critical concentration, about 8 to 10% in the muscle, is reached. Parallelling the rapid denaturation, a sudden increase of salt uptake and of moisture loss occurs." From that observation, we considered it possible to produce lightly salted, minced fish with sufficient functional properties to enable the product to be formed into a cake or portion and therefore more closely resemble traditional salt cod.

Experiment

An experiment was designed to determine the effects of adding different quantities of salt to minced cod. Key factors considered in the study were protein functionality, colour, and water released from the tissue.

A standard test procedure was used wherein a fixed quantity of freshly prepared minced cod was mixed for 5 minutes with five different amounts of sodium chloride (at 5, 10, 15, 20, and 25% of the weight of the mince). The mixtures were then held at 35°C for 30 minutes and were stirred frequently. Released brine was collected through a Buchner funnel with vacuum while the tissue was being pressed to form a cake. The salted cakes were air dried at room temperature in a ventilated fume hood until a moisture content of 30–35% was obtained. Dehydrated cakes were sealed in laminated (polyethylene–aluminum foil) pouches for "curing" and subsequent analyses.

For comparative purposes, the various end-products were subjected to a series of laboratory tests. Protein contents were calculated from Kjeldahl nitrogen values. Sodium chloride levels were determined by conductivity and moisture values from weight losses after oven drying for 24 hours at 95°C. Colour was measured by a Gardner Automatic Color Difference Meter. The dried products were rehydrated by soaking (30-g samples in 10 volumes of water for 4 hours). Subsequent cooking involved boiling each sample in 75 ml of water for 3 minutes.

Results and Discussion

Under the experimental conditions employed, the results indicate that more than 10% salt is required for protein denaturation and the associated loss of water-binding capacity (Fig. 1). Although this level of salt is somewhat higher than that reported by Duerr

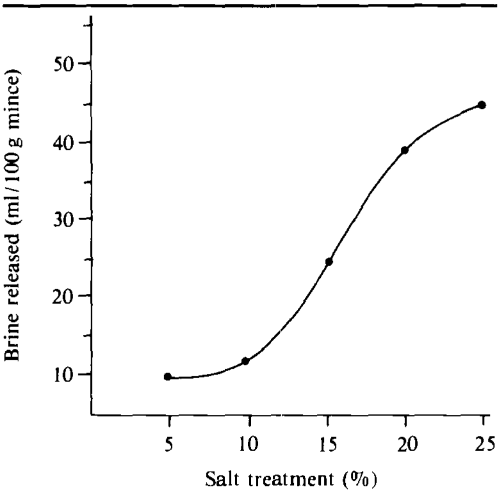

Fig. 1. *Brine released for different salt treatments of minced cod muscle.*

Table 1. Composition, colour, and rehydration values for five salt-treated cod minces.

Parameter	Salt treatment (%) 5	10	15	20	25
Composition (%)					
Moisture	30	30	30	30	30
Protein	55	50	48	44	44
Salt	15	20	22	26	26
Colour[a] **(L)**					
Mean	62.9400	65.2857	68.5475	64.0875	67.9675
SD	±1.1914	±1.8396	±1.2768	±0.6581	±0.7467
Water uptake					
Weight before soaking (g)	28.55	32.53	29.83	28.59	20.14
Weight after soaking[b] (g)	46.99	45.22	54.16	43.94	42.76
Uptake (%)	39.24	28.06	44.92	34.94	31.85

[a]Scale 0–100 where 0 is black and 100 is white.
[b]Soaked 4 hours at room temperature in 10 volumes of water.

Table 2. Composition and colour of rehydrated and cooked samples of salted minced cod.

Parameter	Salt treatment (%)				
	5	10	15	20	25
Composition (%)					
Moisture	66	68	72	67	68
Protein	31	30	26	30	31
Salt	3	2	2	3	1
Colour[a] (L)					
Mean	58.935	60.824	65.574	62.446	61.880
SD	±0.0981	±0.8733	±0.0760	±0.9059	±1.1140

[a]Scale 0–100 where 0 is black and 100 is white.

and Dyer (1952), a time–temperature factor may be responsible.

In the composition of the dehydrated, salted, minced fish products (adjusted to 30% moisture content), the protein content is inversely proportional to the amounts of salt present; therefore, the product containing the least amount of salt contains the most protein (Table 1). Additions of salt at 20% and 25% yielded products saturated with salt, whereas 10% and 15% salt additions produced fairly heavily salted products. The results suggest little advantage in processing with more than 20% salt.

After drying to 30–35% moisture, the cakes were solid and could withstand normal handling without breakage. The cakes from the initial treatments with 5% and 10% salt had rough, coarse surfaces unlike the more fibrous appearance from the other treatments. The samples receiving the higher salt treatments were lighter in colour (Table 1) and, therefore, more closely resembled the natural colour of salted cod. On a scale of 0–100 (where 0 is black and 100 is white), the 15% salt treatment yielded a product at least as white as those from the two higher treatments.

After being stored in sealed pouches for approximately 3 weeks at about 20°C, the salted products acquired the traditional odour of salt-cured cod. The intensity of the odour seemed to increase with the amount of salt in the product.

As a first step in examining the functional properties of the salted products, we examined water uptake at rehydration. The results showed that the product treated with 15% salt had the greatest water-binding capacity (Table 1). Furthermore, this property was retained in the cooked product (Table 2). All samples held together and maintained their cake form throughout rehydration and cooking. Initial examination indicated that the 15% salt treatment yielded a lighter coloured product than did the others. This finding was confirmed by the Gardner Color Meter determinations (Table 2).

Preliminary taste-panel tests on the cooked products indicated that the samples had an acceptable flavour, closely resembling that of traditional salt cod, and that the 15% salt treatment sample appeared to have the best texture.

Although this study is continuing, early results have suggested that the addition of about 15% salt to lean, minced-fish tissue is sufficient to yield a product with superior properties.

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Concentration and Preservation of Mechanically Recovered Fish Flesh

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Preliminary tests in a laboratory, and a pilot-plant test, have shown that the contents of water, volatile bases, and trimethylamine oxide of raw mince separated from cod frames can be substantially reduced by a new process involving the addition of salt, acidifying to pH 4, draining, and pressing. The moist, pressed cake has a long shelf life at 0–5°C when stored without contact with air. It can be comminuted and neutralized with dry soda (Na_2CO_3) in one operation. A subsequent drying will give it a shelf life at 25°C of more than 1 year. The formation of dimethylamine during storage of the dried, neutralized pressed cake is much less than that observed for directly roller-dried mince. Although this study has been limited to cod and wastes from cod filleting, the process and results may prove applicable to the by-catch from shrimp trawling.

To increase yields of fish flesh, filleting plants all over the world now use mechanical deboners or separators that remove skin and bones from the flesh. Such machines have great potential to increase the food use of the fish resources, but, at present, their use is limited because consumers demand that the mechanically recovered flesh or mince be almost white. About two-thirds of the wet weight of the "frames," or backbones left when cod or similar white fish are filleted, could be recovered as boneless flesh, but such mince, which contains bits of the swim bladder and other membranes and is discoloured by blood and kidney tissues, has no market at present for food use. Compared with flesh from V-cuts, the flesh recovered from frames has a high content of water and other elements that accelerate the production of dimethylamine and formaldehyde during preservation and storage. Therefore, it has a low value commercially and is not suitable for salt preservation (Wojtowicz et al. 1978).

A new process has been developed to concentrate and preserve raw fish minces that have a high initial content of water and undesirable, water-soluble components. The process is based on the Canadian observation that a 5% aqueous NaCl solution will not extract proteins from cod flesh acidified to pH 4 (Dyer et al. 1950). The acidity, combined with the salt, creates conditions for the cod proteins to be rapidly denatured, most of their water-binding capacity being lost. Producing this action is the first step in the process; it is followed by draining and pressing of the mince. Some undesirable pigments and nitrogenous extractives such as ammonia and trimethylamine oxide are removed with the water, whereas the loss of soluble protein is little or nil (Dyer et al. 1950). Also, the new process takes advantage of the preservative effect of light salting and acidifying of raw fish, known from traditional fish marinating.

Dewatering Technique

Preliminary laboratory tests indicated that an addition of dry, fine salt and enough 18%-HCl solution to lower the pH to about 4 substantially reduced water-holding capacity of raw cod mince. In one series, gutted cod were stored in wet ice for up to 13 days before being filleted. The fillets were minced, and 0.5-kg portions of the mince were salted and acidified. The amount of water removed from each portion varied little with duration of previous ice storage, water removed after 1 day (265 ml) and 13 days' storage (267 ml) being practically the same. The mince was drained on sieves and pressed in a small hand-operated press.

The early laboratory tests indicated that the removal of water was more efficient at pH 4 than at pH 4.8 and that 2–3% salt was more efficient than 1%. They indicated also that the process reduced the trimethylamine oxide content about as much as it lowered the water content. When the process was used on the flesh recovered from cod frames, it removed

Processing cod frames in a separator drum.

some dark pigments, but the pressed mince came out light brown and was relatively unchanged after being repeatedly washed and pressed. A separator drum having 4-mm perforations proved convenient for the recovery of flesh from cod frames.

The small-scale trials were carried out at room temperature, i.e., about 20°C. Although the small press, operated by hand, produces cakes containing 30–40% dry matter, the use of a continuous screw press belonging to a small-scale, fish-meal plant could increase the dry-matter content to about 50%.

The results of the laboratory tests were the basis for the procedures in the pilot plant; the steps include:

- Processing small cod frames in a separator drum with 4-mm perforations;
- Adding 3.25% half-concentrated HCl to bring the pH below 4;
- Adding 4% dry, fine salt to the mince;

- Allowing the mince to drain on a sieve for about 1 hour;
- Pressing the mince on a single-screw press; and
- Breaking the pressed cake in a Stephan Universal machine.

More than 100 kg of mince was processed in the pilot-plant test. From 100 kg of raw mince containing 84% water was produced 28 kg pressed cake containing 49% water — a removal of more than 80% of the original water content. The water contained a slurry of fine particles that were not recovered.

Part of the comminuted, pressed cake was divided into 500-g portions and vacuum packed in airtight, plastic pouches for subsequent storage trials at 0°, 5°, 12°, and 22°C.

Samples of the vacuum-packed, pressed cake remained below pH 4 for more than 1 month when stored at 0°, 5°, or 12°C (Fig. 1).

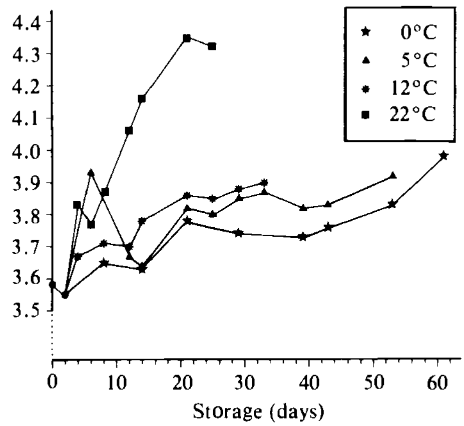

Fig. 1. *Changes in pH during storage of pressed cake at 0°,5°,12°, and 22°C.*

The total viable bacteria of these samples decreased sharply within the first week of storage, and the bacterial counts for the samples at 0°C and 5°C remained low for 2 months. The samples at 12°C had moderate increases in bacterial counts after 3–4 weeks (Fig. 2), and those at 22°C had rapid increases. Slow-to-moderate increases occurred in the contents of total volatile base nitrogen (TVN) in the chilled samples, whereas the TVN contents of the samples at 22°C increased rapidly (Fig. 3). Thus, storage life at 22°C is limited to a couple of days; at 12°C perhaps a couple of weeks; and at 0–5°, probably 1–2 months. It is noteworthy that the initial TVN content of

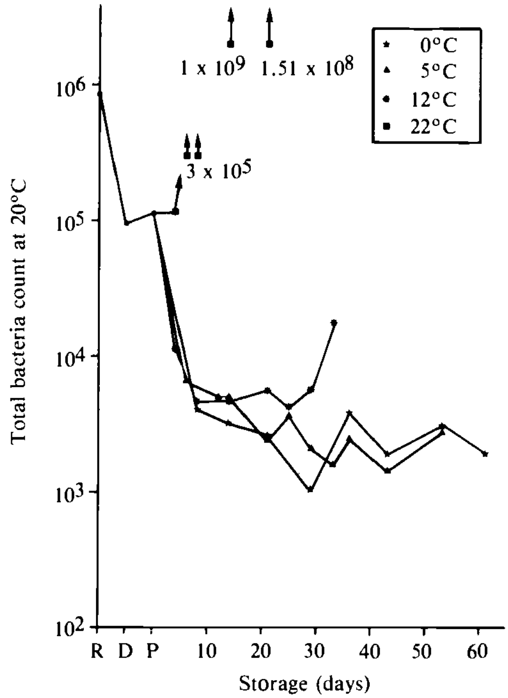

Fig. 2. *Total bacteria count of pressed cakes during storage at 0°,5°,12°, and 22°C.*

pressed cake is lower than that for mince and for some traditional dried-fish products. The content of trimethylamine oxide (TMAO) is also low as a result of the substantial reduc-

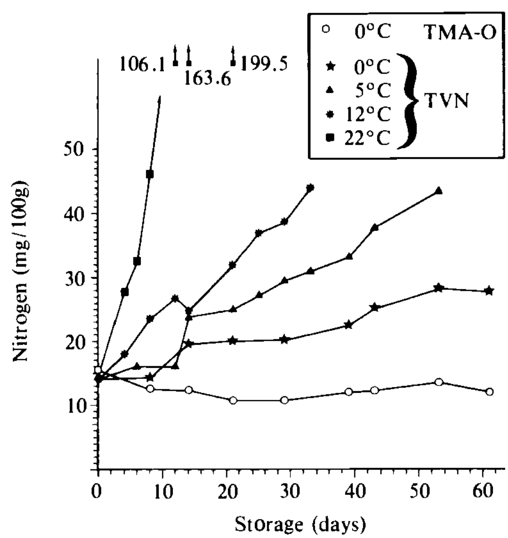

Fig. 3. *Increases of total volatile base nitrogen of pressed cakes during storage at 0°,5°,12°, and 22°C.*

tion of water and water-soluble contents during the processing (Fig. 3).

Neutralized Pressed Cakes

Portions of pressed cake were treated with fine soda (Na_2CO_3, water-free), and the pH was monitored as an indicator of the amount of soda needed to neutralize the cake. The pH of the cake decreased within a day of soda addition, indicating a less than complete mixing effect. A further decrease was seen after the cake had been dried and stored at 25°C for 7 months (Table 1). These findings indicate that one should add enough soda to bring the pH initially to nearly 8.

Some neutralized pressed-cake samples were dried in an air blast at 55°C; the process turned the fibres light brown and the material was about 84% protein, 6.5% salt, and 7.5% water. It was not too salty to be eaten directly. Roller drying produced darker and tougher fibres than did air drying.

A small number of air- and roller-dried, neutralized pressed cakes, all produced from cod-frame mince, were stored at 25°C for about 7 months, in some cases together with directly roller-dried mince. All the dry samples were stored in polyethylene bags or beakers in contact with air. None of them developed mould or other marked changes during storage. Increases in the contents of dimethylamine (DMA) were thought to represent a stochiometrically equivalent formation of formaldehyde, which is undesirable as it may cause a small decrease of protein availability during storage. The samples that had been almost completely neutralized by the addition of Na_2CO_3 showed the lowest DMA contents, and samples air dried at 55°C showed slightly lower DMA contents than did the roller-dried ones (Table 2). These trends support earlier findings in samples that had been processed in the laboratory and had been stored for 7 months. In one series, the DMA content of air-dried, pressed-cake samples was about 12 mg/100 g, whereas that of a roller-dried sample was 30 mg/100 g. The directly roller-dried mince contained 67 mg/100 g. In another series, including only roller-dried samples, one sample, showing pH 6.9 contained 24 mg DMA/100 g, and another, showing pH 6.6, contained 31 mg DMA/100 g. The directly roller-dried mince of this series contained no less than 108 mg DMA/100 g after 7 months' storage at 25°C.

Table 1. Changes in the pH of Na_2CO_3-treated pressed cake.

Na_2CO_3 (g/kg)	pH after treatment	pH a day later	pH after drying, storage 7 months
12	5.7	5.1	–
16	6.6	6.3	5.8
18	6.9	6.6	6.2
20	7.3	6.9	6.6
24	7.8	7.5	7.2

Table 2. DMA contents in Na_2CO_3-treated pressed cakes after 7 months' storage.

Air-dried samples		Roller-dried samples	
pH	DMA (mg/g)	pH	DMA (mg/g)
5.8	15	5.8	21
6.2	16	6.1	18
6.7	15	6.6	18
7.2	13	7.2	14

These storage trials indicate that — compared with direct roller drying — salting, acidifying, and pressing mince results in a substantial reduction of the DMA formation during long-term storage. They also indicate that the reduction of the DMA formation is more efficient in neutral than in acid pressed cakes and that air drying at 55°C is preferable to roller drying.

A major advantage of this process is that the early stages, which require only simple and cheap equipment, preserve the fish against rapid microbial spoilage. As soon as the wet mince is acidified to pH 4 and lightly salted, it will keep for a number of hours at normal room temperature, for many days at 12°C, and for many weeks at 0–5°C. If the mince is allowed to drain in sieves, the water content will be decreased, and the bulk will be greatly reduced. This simple process should prove advantageous to small plants along the coast or even to vessels at sea.

The pressed cakes need only be dried when they have to be stored for a long time before being further processed or prepared for consumption. When intermediate storage is short, the drying may be omitted and the chill-stored, moist pressed cake used as a food ingredient.

The industrial equipment required in the new process can also be used to produce "instant" salted, minced fish (Mendelsohn 1974), i.e., comminuted pressed cakes: a salt/mince mixture (1 : 3) that is drained and pressed. This process is applicable to a large number of fish species (Del Valle and Gonzalez-Inigo 1968).

After a year's storage at ambient room temperature in contact with air, the air-dried, pressed cake from the pilot-plant production remained light brown with a light odour and flavour like traditional dried cod. The new product has a high protein content and a low content of nonprotein-nitrogen such as ammonia, amines, and trimethylamine oxide, which are undesirable in food. It contains only a few percent of salt, and it can replace traditional dried cod in a number of widely used recipes where comminuted, dried fish is an ingredient. It can also replace dried or fresh fish in the traditional keropok (kroepoek) or fish cracker. This is dried starch–protein flakes that expand and become crisp when fried in oil. The crispness of these flakes does not depend on the functional properties of the fish ingredient (Yu et al. 1981), and these flakes are widely used in Southeast Asia, according to Yu et al. (1981).

The neutralized, moist or dried, pressed cake may also be considered for use as fish extender, e.g., for mixing with fresh fish mince. Such mixes may be considered for the development of semimoist, lightly salted products of the salami type.

Conclusions

At this stage, the new process appears to provide good storage life and retention of the nutritional values of mechanically deboned fish. The functional properties, however, such as water retention and gel-forming capacity of the products, are poor. In this context, it is recommended, therefore, that the neutralization method and other processing parameters be further studied. Attempts should be made to increase the protein yield by the use of alkali to extract protein from the fish-bone fraction before the pressed cake is neutralized. When the new process has been further developed and the optimal processing parameters have been established, pilot plants should be established to study the suitability of the process for raw materials such as by-catch from shrimp trawling.

Processing of By-Catch into Frozen Minced Blocks (Surimi) and Jelly Products

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By-catch fish from shrimp trawling were used for pilot-scale production of frozen surimi and fish-jelly products. The technology developed was then transferred to fish processors and fish technologists in Southeast Asia through demonstrations and training courses.

A major portion of the catch by fish and shrimp trawlers operating in the Southeast Asian region comprises fish species classified as by-catch that are discarded at sea or converted to animal feed. A considerable increase in by-catch has been reported from most Southeast Asian countries in recent years, ranging from 40% to 70% of the total fish catch (JICA 1978). An estimated 5×10^6 t of fish by-catch are discarded at sea in the tropics (Allsopp 1977), and more than 10^6 t were caught in the South China Sea area alone in 1978 (SEAFDEC 1980).

With the reported increase in the amounts of the by-catch and the alarming estimates of discards at sea, the problem of using this resource for human consumption is of immediate concern for the region and is the basis for a project undertaken by the Marine Fisheries Research Department of the Southeast Asian Fisheries Development Center. The major thrust of the project includes pilot-scale production of frozen minced blocks (surimi), production of traditional fish-jelly products of the region, and basic studies on the gel-forming ability of common species in the by-catch. In addition, nonjellied products such as fish fingers have been investigated.

Method

Fish by-catches from commercial trawlers in the South China Sea were purchased from the local fish market in chilled form and were placed in ice water as soon as they were brought to the laboratory. They would normally have been used for livestock and fish feed and for conversion into fish meal; therefore, much of the material had not been satisfactorily iced, the degree of freshness varying according to whether the fish were caught at the beginning or end of the fishing trip, which usually lasts 3–5 days. The fish were purchased at a contract price of S$0.50/kg, including transport and delivery charges. The market price, however, fluctuates according to the supply, with an average of about S$0.30/kg (without delivery).

Although the by-catch of the area comprises at least 100 species, the major components are goatfish (Mullidae), croaker (Sciaenidae), threadfin breams (Nemipteridae), lizard fish (Synodontidae), silver biddy (Gerridae), ponyfish (Leiognathidae), and Parapercidae, together constituting about 80% of the total weight (Sinoda et al. 1978). Despite the variations in species composition and amount according to season, locality, degree of sorting on the vessel, etc., a significant portion of the fish may be used for human consumption.

One of the limitations on the use of the by-catch is that the fish are small and difficult to head and clean. In countries where labour is cheap, the operations can be done by hand, but, for handling in bulk in other areas, mechanical heading and gutting would be necessary.

The Marine Fisheries Research Department, therefore, tested the use of a modified fish heading–filleting machine. The machine, which can be used for fish ranging from 30 g to 200 g can reduce the time for heading and gutting by half.

The use of a mechanical flesh-and-bone separator appears essential for bulk handling of by-catch as raw material, especially in areas where labour is costly. With the use of this equipment, a yield of mince at about 35% (by weight of whole fish) can be obtained from the by-catch. The mince, however, is usually dark red because of blood and kidney tissues that have not been completely removed during gutting.

This mince must be treated further. One method to improve it is washing. It was found that, when the mince was washed twice with 4–5 times its volume of iced water (w/w), first with 0.2% salt and then with 0.3% salt, the leaching confers several advantages; it:

- Gives the flesh a higher gel-strength potential, by removing the undesirable components that interfere with gel formation;
- Whitens the product;
- Removes the fishy odour — taste can then be adjusted to suit local preferences through the addition of, for example, monosodium glutamate, spices, taste enhancers, etc.; and
- With addition of sugar, enables the mince to be frozen and stored for an increased period.

When the mince has settled, the excess water is discarded, and further dewatering can be achieved by hydraulic or screw press or by centrifugation. For the hydraulic press, the mince is placed in a nylon mesh bag and subjected to pressure of 14 kg/cm^2 for about 10 minutes. Basically, the equipment can be a hand-operated press, oil-compression press, lever system, or even a modified car jack. This system is basically a batch process and is usually slow but suitable for small-scale manufacturers. The screw press is more expensive and sophisticated; it forces the mince forward as the water oozes out through the fine mesh along the sides. The mince is finally extruded quite dry at the end. This is a continuous method and is suitable for large-scale production or for surimi manufacturers. Centrifugation is essentially a batch process. Dewatering occurs when the mixture is spun at 2000–3000 rpm for about 10 minutes. This method is efficient and is suitable for small to medium-sized manufacturers. Depending on the method of dewatering and adjustment of the machinery, the moisture of the final material is about 80–82%.

In Japan, the conventional technique to reduce denaturation of surimi during freezing and storage is to add 8–10% sugar and 0.2% polyphosphate to the leached mince (Tanikawa et al. 1969). Under pilot-scale conditions, leached mince from by-catch (with 3% sugar and 0.2% polyphosphate) has been kept for at least 6 months at -25° to -30°C in the Department. It is, therefore, possible to use less sugar (3%) than was previously felt necessary for surimi made from tropical fish species. This finding is important in Southeast Asia where consumers are not familiar with sweet fish-jelly products. For shorter periods of storage, the leached mince can be kept chilled in ice or partially frozen (ice/salt mixture at -3°C).

Processing of Frozen Surimi into Jelly Products

The leached mince in either the fresh or the frozen (surimi) form has been used by the Department for making a wide range of jelly products. In the Southeast Asian region, the most popular traditional fish-jelly products are fish balls and fish cakes. With the increase in price of raw materials used traditionally for these products, the fish-jelly product industry has to utilize other fish. The introduction of leached mince from by-catch and low market-value fish as a substitute raw material will provide impetus to the development of the industry in the region, as well as increasing the utilization of an abundant resource for human consumption.

The Department has successfully produced, on a pilot scale, fish balls and fish cakes from surimi made from by-catch. The products are white and of high quality with good *ashi* (elasticity). Evaluation studies through trial sales at a local supermarket showed that the products were widely accepted by local consumers. In addition, the technology developed has also been transferred to manufacturers, fish technologists, and extension officers in the region. The Department has already received several requests for technical assistance from both commercial and government organizations.

Processing

The blocks of frozen surimi were kept overnight in a chilled room and then ground with other ingredients in a cooled mortar-and-pestle grinder for about 25 minutes. The other ingredients included salt (2.5–3%), flour (wheat, potato, or cassava — 3%), monosodium glutamate (0.5%), and water (20–80%, the amount depending on the moisture and quality of the surimi). The paste was then formed into the products by machines for making fish balls, fish cakes, fish rolls, etc., although these products can also be formed by hand. The products were then "set" in tap water (28–30°C) for 2 hours or 40°C for 20–40 minutes, before finally being cooked at 90–95°C for 20 minutes.

Basic Concepts of the Project

In initiating the project on the utilization of by-catch as a raw material for the production of traditional fish-jelly products in Southeast Asia, the Research Department has introduced several basic technological concepts:

- Leaching of mince, which is one of the most important steps in the production of fish-jelly products; washing eliminates the components that interfere with gel formation and makes it possible to utilize not only a wider range of fish species but also raw materials that are not fresh. Cheap and abundant fish resources can now be processed into fresh or frozen mince for the production of good quality fish-jelly products (Poon et al. 1981).
- Use of frozen surimi as an intermediate product; frozen surimi has been widely used in Japan for the manufacture of fish-jelly products (kamaboko) from an abundant and underutilized fish resource, Alaska pollack (Matsumoto 1978). The production of frozen surimi in Southeast Asia, as an intermediate product, can help stabilize the availability of raw materials for the fish-jelly products industry; provide the basis for centralization of treatment of raw materials (including problems of waste discharge and disposal); increase utilization of by-catch mince, even as meat extenders in sausages, burgers, etc.; aid in the development of new products; be useful in areas where seasonal abundance of some low-value fish species gives rise to problems in utilization and preservation; and give manufacturers greater flexibility in production and process planning.
- Double-step heating of the products; determining the optimum conditions (temperature and time) for "setting" are important if the potential gel strength of the raw material is to be realized. This is especially important because the proteins of tropical fish behave rather differently from those of temperate fish species. Traditionally, the products are soaked in tap water (28–30°C) for 2–3 hours before being boiled or fried; however, the time can be reduced to 20–40 minutes at a temperature of 40°C. An understanding of the setting conditions of the different species is, therefore, necessary for greater flexibility in production and process control.

Training and Transfer of Technology

One of the primary functions of the Department is to transfer technology to fish technologists and processors in the region. This is done through training and lecture-cum-demonstration courses.

Since August 1980, the Department has conducted four short-term training courses for fish technologists from Southeast Asia. Participants included technologists involved in research in fish processing, product development, and extension services. So far, 24 participants from Thailand, the Philippines, Malaysia, Singapore, and Brunei have completed the courses. The courses covered, among other subjects, the basic principles of processing fish-jelly products, principles of gel formation of fish flesh, and practical sessions on processing of frozen surimi and fish balls and cakes. Assessment of fish-jelly products and fish freshness was also included.

The main objective of other, lecture-cum-demonstration, courses is the extension of the technology suitable for upgrading of the fish-ball and fish-cake industry in the region. The Department organized four such courses, of which one was for processors from Southeast Asian countries. The courses dealt mainly with the technology for utilizing low-value demersal fish for the manufacture of fish-jelly products and their intermediate products, covering:

- The effect of proper leaching of mince to improve the gel strength and colour of the product;
- The effect of double-step heating in production of fish-jelly products and the importance of correct temperature and time;
- The rationale for utilizing surimi (frozen blocks of mince made from underutilized

fish) and its production and preservation;
- Formulation and production of a range of fish-jelly products from underutilized fish and frozen surimi; and
- Demonstration of fish-processing equipment for the production of surimi and fish-jelly products.

Of the total participants, 116 were local and 17 were from Malaysia, Thailand, and the Philippines. The demonstration provided the manufacturers with the opportunity to compare and discuss processing methods and equipment and to assess the applicability of the technology to local conditions. As a result, the Department has now established close rapport with local manufacturers and has received a number of requests for technical assistance and guidance. Local factories are visited periodically by officers from the Department to deal with specific problems and to monitor and assist in efforts to incorporate the technology. Already, one small producer has successfully begun producing fish-jelly products such as fish balls and cakes from small demersal fish using technology developed by the Department.

Development of a Salted, Minced Product from Mexican Shrimp By-Catch

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The technique of rapid salting and dehydration may be applied to deboned minces obtained from shrimp by-catch to prepare a stable, low-cost food suitable for distribution in rural or urban areas. The process involves mixing the deboned mince with 20% (w/w) salt, cooking the mixture, and drying it at low temperatures. The cooking considerably reduces drying times and improves the appearance, flavour, and mechanical properties (including texture) of the product, which can be stored at ambient temperatures without adverse effects on its microbiological or organoleptic quality. Moreover, the high food value of the fish protein is retained even after storage for several months. When the product is soaked and boiled, it is reconstituted and can be used in a number of recipes. Market tests have indicated favourable consumer responses toward the product.

Initially, the general objectives of processing studies on Mexican shrimp by-catch were:

- To maintain processing costs as low as possible;
- To develop products with maximum retention of nutritional value;
- To develop products with good keeping qualities in the absence of refrigeration or freezing; and
- To develop products acceptable to the Mexican consumer.

In view of the nature of the by-catch, i.e., a complex mixture of small demersal fish, mechanical deboning was considered an appropriate preliminary operation that would permit the fish to be converted into food products for local distribution.

Previous work on the development of dried fish products included the drying of precooked minces (Cutting et al. 1956) and mixture of comminuted fish flesh with salt for effective and simple preservation (Del Valle and Nickerson 1968; Andersen and Mendelsohn 1972). Salted minces may be pressed, dried, and stored for long periods at ambient temperatures without risk of spoilage. At ITESM, this salting and drying principle was applied to deboned by-catch minces and the procedure modified to improve rehydration, texture, and flavour of the final product.

Product Development

The technology comprises two stages — mechanical deboning and product formulation. Elimination of the bones, skin, and scales of by-catch fish has been carried out on a pilot scale with a Paoli automatic flesh-and-bone separator, which produces a finely minced flesh. The comminuted fish flesh is initially mixed with a high concentration of salt. This promotes a loss of water-holding capacity of the muscle proteins and provides immediate protection against spoilage. It is important to control salt concentration to obtain adequate drying rates and acceptable texture and colour in the product. Addition of 20% (w/w) salt to the mince promotes optimum product characteristics. The speed and time of mixing the fish with salt are also critical, affecting the binding properties of the mixture.

Originally, the salt–fish mix was simply pressed into cakes and dried at a low temperature (40°C) in ovens. Drying times were lengthy, usually 50–60 hours. Later, it was found that, if the mix was cooked before being dried, drying times were reduced and appearance, flavour, and texture of the product were further improved (Young et al. 1979). Moreover, the cooking eliminates the need for pressing the wet minces and discourages undesirable changes in colour and flavour during dehydration and product storage.

Heating at 70–100°C for 1–2 hours, then drying at 40°C, reduces the drying time to 30 hours. Samples heated at 100°C for 1 hour and subsequently dried at 40°C exhibit the optimal organoleptic properties (Young et al. in press). It should be possible to increase drying rates with appropriate commercial equipment.

Microbiological Aspects

Microorganisms in the fish mince were enumerated at various stages during processing (Young et al. in press). Fish with a high bacterial load were used in experiments so that the effects of the process could be easily observed. Higher counts of microorganisms are found in the deboned mince than in the raw material, but, on addition of 20% salt, the counts decrease and eventually fall to fewer than 10 organisms/g after cooking and drying. The process, thus, virtually sterilizes fish minces, and the dried product remains sterile even after several months' storage at tropical temperatures. Bacterial counts in the final product are equally low whether gutted or whole, ungutted fish are used as raw material.

Product Characteristics, Composition, and Nutritive Value

An important function of this technology is that it confers texture on the finely ground tissue so that the final product is of meaty consistency. Taste-panel testing has indicated that this effect is more pronounced when cooking is carried out for 1 hour at 100°C.

Precooked cakes are normally regularly shaped, smooth-surfaced, light-coloured, pleasant smelling, and compact. Uncooked cakes tend to be darker, less regular, and less compact, having a granular surface and a stronger odour.

The salted fish cakes contain almost 50% (dry weight) protein, and the fat content is low. Nutritional studies have demonstrated good retention of essential amino acids and high protein quality of the product (Young et al. in press). Freshly prepared products have a net protein utilization (NPU) between 86.3 and 91.5, a level comparable with that for egg protein. Varying the processing conditions has little effect on the NPU, although some reduction in protein quality occurs during storage. Nevertheless, even after 6 months' storage at ambient temperature, NPUs of 75 have been recorded in the product, this value slightly exceeding that of beef muscle.

Reconstitution and Preparation for Consumption

The final product is soaked and boiled before being eaten. Salt is thus removed, and the reconstituted cakes have no salty taste. Increased in bulk, these cakes contain approximately the same quantity of protein as fresh fish (16–20%).

Cakes that have not been cooked during their manufacture tend to disintegrate on reconstitution. Precooked cakes have superior mechanical properties and remain intact during preparation. They are suitable for various traditional food preparations, having a texture similar to cooked, minced meat.

Acceptability and Market Testing

Initial studies assessed general acceptability and compared precooked and uncooked cakes (Young et al. 1979). Taste panels were drawn from ITESM staff and lower-income residents of Guaymas. A popular recipe was used with locally available ingredients. Tasting took place at four separate sessions, with groups of 10–20 assessors. Despite the general acceptability of all products, the results from the panels indicated a significant preference ($P<0.01$) for meals incorporating precooked cakes. Comments indicated that their flavour and texture were preferred.

This initial study formed the basis for more extensive market testing of salted fish cakes in Mexico. The subsequent tests covered a wider range of consumers, evaluating response to the product, projected price, and other factors associated with presentation and preparation. A recipe booklet was produced for these trials.

Testing in local supermarkets has provided promising results. Through a questionnaire, about 600 homemakers were interviewed, and the results indicated good market potential for the product (ITESM 1980). Flavour and odour were judged to be especially attractive.

For testing of home usage, samples of the product and a recipe booklet were left in 51 homes, and the homemakers were subsequently interviewed (De Villa and Associates

1980). The product was well accepted, and 90% of the homemakers stated that they would be willing to pay at least 5 pesos per fish cake. This price is well above the projected selling prices for the product, suggesting that its low cost may be particularly advantageous.

Commercialization

These results have encouraged the development of commercial operations, particularly because an appropriate marketing infrastructure already exists in Mexico. Under Sistema Alimentario Mexicano, emphasis will be directed to the efficient distribution of food products to all regions of the country, and the state trading company CONASUPO (Sistema de Distribuidores Conasupo) has retail outlets stocked with basic foods to supply the lower-income groups. There are several thousand rural and urban shops, and more are being set up in cooperation with COPLAMAR (Coordinación para el Desarrollo de las Zonas Marginales). Another government organization — DIF (Sistema Nacional para el Desarrollo Integral de la Familia) — provides nutrition education and distributes cheap and basic foodstuffs. These organizations serve as channels through which this dried, salted fish product may be widely distributed throughout the country.

Canned, Frozen, and Dried Products from By-Catch Fish

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The development of new products based on deboned minces from Gulf of California shrimp by-catch is described, illustrating the versatility of the raw material. These products closely resemble others that are now marketed in Mexico and that are usually prepared from meat or high-quality fish. This approach was geared at potential consumers who are traditionally reluctant to buy and try new products. Canned products developed include pâtés or spreads (commonly based on liver or meat) and skinless Vienna-type sausages in brine (traditionally pork). Frozen products include breaded fish sticks (usually based on fish fillets) and a fish croquette. Dried products include fish soup with vegetables and a savoury mince mixture similar to a Mexican product called picadillo, which is prepared from minced beef. Two snack products — fish biscuits and fish crackers — have also been developed.

The existence of canning and freezing technologies and an improved food distribution system in Mexico has meant that the consumers, even in inland areas, are now exposed to the wide variety of processed products available, some of which are prepared from fish. Consequently, a number of products have been developed at ITESM in Guaymas based on deboned minces from by-catch fish. The methods of manufacture were designed to meet existing food-factory design and equipment requirements. It is hoped that this approach and the low cost of the raw material will result in the production of high value, low-cost foods.

Fish Materials

By-catch fish were obtained from commercial trawlers during the latter half of the 1980–81 season. Deboned minces were prepared from a range of fish species that are frequently found in the by-catch. These fish were gutted, cleaned, and then deboned with a Paoli deboning system (model 19-529). Another raw material included in the developmental work was deboned mince prepared from frames remaining from commercial filleting operations. This material can constitute a waste-disposal problem in Mexico; yet, high-quality minces were recovered when a Baader-694 deboner was used.

Product Development

Canned products

Two canned products have recently been developed (Table 1). One is a pâté or spread similar to Mexican liver or meat pâté and the

Table 1. Ingredients in two canned products.

Ingredients	Pâté (%)	Sausage (%)
Paoli-deboned minces	67.0	69.0
Trisodium polyphosphate (0.15g/ml)	2.2	2.3
Fat		
Butter	10.5 5.3	–
Margarine	10.5 or 5.3	–
Hydrogenated soybean oil	– 10.5	10.0
Maize starch	–	10.0
Ground, toasted bread	8.0	2.5
Wheat flour	–	2.5
Gelatin	–	1.0
Sugar	–	1.0
Garlic salt	1.0	1.0
Ground pepper	0.7	1.0
Lime juice	0.7	–

Table 2. Ingredients in two frozen products.

Ingredients	Stick (%)	Croquette (%)
Paoli-deboned minces	95.5	55.3
Trisodium polyphosphate (0.15g/ml)	3.2	1.8
Maize starch	–	9.5
Potato flour	–	4.8
Water	–	25.5
Garlic salt	0.7	1.6
Ground white pepper	0.7	0.6

Table 3. Ingredients of four dried products.

Ingredients	Soup (%)	Picadillo (%)	Cracker (%)	Biscuit (%)
Paoli-deboned minces	32.1	49.9	35.7	26.0
Water	32.1	–	25.0	10.4
Hydrogenated soybean oil	2.3	8.0	–	–
Fresh onion	20.6	24.9	–	–
Maize starch	5.9[a]	–	35.7	–
Wheat flour	–	–	–	52.0
Whole egg	–	5.0	–	–
Maize oil	–	–	–	10.4
Skim-milk powder	2.4[a]	–	–	–
Soy sauce	0.4	–	–	–
Tomato purée	–	8.0	–	–
Salt	2.7	1.5	1.4	1.0
Pepper	0.4	0.5	0.3	0.2
Paprika	–	0.75	–	–
Turmeric	–	0.5	–	–
Ginger	–	0.5	–	–
Cumin	–	0.5	–	–
Sugar	–	–	1.8	–
Dextrose	1.1[a]	–	–	–
Ascorbic acid	0.15[a]	–	–	–

[a]These ingredients were added to the previously dried and ground soup mix.

other similar to a popular meat sausage. Paoli-deboned minces were found to be ideal for inclusion at high proportions into these emulsified products.

Ingredients are cut in a silent-bowl chopper until smooth. The sausage mixture is stuffed into 2-cm cellulose casings and set in boiling water. The sausage coils are cut and packed in cans that are then filled with hot brine. The pâtés are placed in the same sized cans and preheated to a core temperature of 70°C. All cans are immediately sealed and processed in upright retorts.

Taste trials indicated that there were no major differences in the acceptability of canned products prepared from different fish species or from filleted frames. The flavour of pâtés was well liked and was not found to be strongly fishy. Pâtés can be sliced and, yet, are easy to spread, although the type of fat used affects this characteristic. Sausages were found to be bland and may be improved if pork lard is substituted for the soybean oil.

Projected designs and financial analysis of a pilot plant for the utilization of shrimp by-catch (Young and Marter 1981) have indicated that the cost of these products would be substantially less than those of equivalent products currently marketed in Mexico.

Frozen products

Breaded fish sticks prepared from water-washed, deboned minces have been developed (Table 2). However, because of the nature of the minces, texture is uniform and spongy, and the fish sticks prepared from certain species are unacceptably dark. Thus, a new frozen product, fish croquette (Table 2), was developed, and it reduced this textural problem. Also, this product does not have to be frozen or breaded before flash frying because a crisp coating is formed during this step.

Dried products

Dried products that have been developed from by-catch deboned minces include soups, savoury minces, expanded maize crackers, and biscuits (Table 3). In the preparation of soups, the minces are cooked with seasonings, mixed with fried onion, and then dried and ground finely. Dried, blanched vegetables may also be added. Taste trials with the reconstituted soups (water/soup ratio 6 : 1) have indicated that the mix is unaffected by the type of fish used. All products were judged acceptable (score 6.91 ± 0.29 SD, n = 70, on a 10-point scale).

It was felt that a product similar to picadillo could be developed from deboned fish minces. The product was developed in a dried form to reduce production costs and bulk for transportation. Spices are added to the mixture for a traditional flavour. The product is texturized by the addition of whole egg and steam cooking. Fresh vegetables can be added during preparation.

Snack products are popular in Mexico. Two products have, therefore, been developed for this market. One of these is an expanded fish cracker that simulates the light, crunchy product prepared from pig skin — Chicharron. The dried crackers, which have a protein content of about 15%, have a long shelf life. Artificial colourings and flavours have also been added, and the cooked crackers are highly acceptable.

Savoury biscuits that include deboned minces have also been developed at ITESM. Deboned minces from different fish materials have yielded dried snack products with similar organoleptic qualities.

Conclusions

Deboned mince from a range of by-catch fish can serve as an appropriate base for the production of low-cost foods with high nutritive value. Minces from filleting frames could provide a source of raw material during the closed season on shrimping. Projections of costs compare favourably with currently marketed alternatives in Mexico.

Acceptability and Storage Characteristics of Frozen, Minced Products from Mexican By-Catch

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Deboned, minced products in frozen form are one focus of the shrimp by-catch program at ITESM. Our studies examined the suitability of selected species for processing and storage as frozen fish minces. Reductions in the extractable, salt-soluble proteins occurred to various degrees in the minced flesh of all the species studied during storage at -10°C and -20°C. These changes minimally influenced the texture of the minces. Considerable variability in the colour of minces from different species was apparent, and a washing procedure has been developed to remove dark pigments. Washing may standardize the properties of minces prepared from mixtures of by-catch fish species. Market testing of breaded fish sticks elaborated from these minces has provided promising results. Thus, deboning followed by freezing offers a potential means of converting currently wasted by-catch fish into human food.

As part of the joint ITESM/TPI shrimp by-catch project, studies have been carried out on the freezing of deboned minces prepared from fish species commonly found in the by-catch from the Gulf of California. Secondary processing into breaded fish sticks could be an appropriate means of introducing new fishery products into the Mexican market, especially as children's food. The studies assessed the suitability of different species for processing into frozen minces and examined the characteristics of the minces during storage. Biochemical changes occurring during storage may subsequently influence the texture and sensory properties of the fish minces (Sorensen 1976). Attention has also been devoted to the possibility of using a mixture of fish species in these products as a means to minimize the sorting of the by-catch. In this context, washing has been evaluated as a technique for standardizing the minces. Processes for manufacturing acceptable breaded fish sticks from frozen by-catch minces have been developed, and some market information on the products is available (Tableros and Young 1981; Young and Tableros in press).

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Preparation of Products

For experiments on storage, fish were headed and gutted by hand, with particular care being given to the removal of the swim bladder, kidney tissue, and excess blood. Fish were then thoroughly washed and stored in ice until deboning by the Paoli flesh-and-bone separation system. The deboned flesh was packed in rectangular, metal trays and frozen at -40°C. Later, the flesh was removed from the trays and cut into rectangular portions, which were wrapped individually in aluminum foil and stored at -10°C or -20°C.

In the flesh-and-bone separation system, the fish are initially ground by a heavy-duty mincer. Washing has proved useful at this stage, promoting a uniform product. The washed mince is then deboned. This technique was used in the products prepared for both storage and market testing, but we incorporated salt, garlic and onion salts, and pepper into the deboned mince for market tests. We found that the concentration of each condiment may be varied between 0.7% and 1.0% (w/w), the total amount not exceeding 3% (w/w). After being frozen, this mince is ready to be processed into fish sticks. The frozen blocks are cut into rectangular portions (1.5 cm × 2 cm × 10 cm) and each portion dipped in batter and bread crumbs. The breaded sticks are then flash fried in deep fat for 1 minute until they are golden brown. They then can be refrozen and stored at -25°C.

Even when care is taken to remove visceral tissues and excess blood from the fish abdominal cavity, the minces from different by-catch species vary in colour. Minces prepared from bronzestriped grunt or rayadillo (*Orthopristis* sp.), a common fish in the by-catch of the area, are particularly dark. Other species, such as flatfishes (Bothidae) and orangemouth corvina (*Cynoscion* sp.), provide light-coloured minces. Darkening effects are probably caused by contamination of the mince by pigments from the skin of the fish or by the presence of greater concentrations of heme compounds associated with the flesh of certain species.

In an attempt to remove pigments from the fish mince, we devised a washing procedure that is carried out in two stages on the material recovered from the mincing section of the Paoli flesh-and-bone separation system. Washing is easier if done before deboning, and losses of solids during the procedure are minimized. The ground fish is stirred in distilled water in a stainless steel tank lined with cheesecloth. Throughout, the temperature should be maintained at 3 ± 2°C by the addition of ice. In the first washing stage, the ratio of mince/water is 1 : 2, and, in the second stage, equal parts of mince and water are used. Each stage is 10 minutes, and the water–mince mixture should be stirred gently and continuously. After each stage, the cheesecloth holding the mince should be lifted from the water and squeezed by hand. This washing technique lightens the colour so that washed minces prepared from various mixtures of by-catch are relatively uniform.

Biochemical and Organoleptic Changes

Protein aggregations may occur in minced fish muscle stored at low temperatures, altering the texture of the minces and lowering their acceptability for food uses. Our studies examined the extent of the changes in frozen minces prepared from different by-catch fish species; the storage characteristics of mixtures of fish species; and the influence of washing the mince.

Reductions in extractable protein nitrogen (EPN) and water-holding capacity (WHC) occurred in the fish minces during prolonged storage (up to 6 months) at -10°C or -20°C. The losses appeared to be species dependent and did not seem to be caused by formaldehyde (Amano and Yamada 1964) because production of dimethylamine and formaldehyde in the flesh during storage was minimal. Despite the losses, only small changes in textural characteristics were observed during frozen storage, and acceptable scores have been obtained in taste-panel tests carried out at intervals during storage.

Mince washed before being deboned appeared less susceptible to deterioration during frozen storage than was unwashed mince. The EPN losses were minimal, and the texture remained stable. Moreover, the washed mince was generally smoother and softer than was unwashed mince. The drawback was that washing promoted flavour losses and introduced an effluent to the process.

Commercialization

Market testing of breaded fish sticks prepared from frozen by-catch minces was carried out in local supermarkets. The results indicated good market potential for the product. The cooked product was judged as very good to excellent, and scores indicating the consumer's willingness to purchase were high. In general, the Mexican consumer is not familiar with the product concept but seems to be attracted to the ease of preparation of the product and its complete lack of bones. In the trials undertaken so far, texture has not been a particularly important consideration for the consumer. More emphasis has been placed on odour and flavour, regularly cited as the preferred characteristics of the fish sticks. In this respect, the condiments that were added to the washed minces seemed to be especially beneficial.

Additional market information has indicated that the local demand for this kind of product is steadily increasing. Particularly advantageous characteristics of the product are that it is convenient to prepare, it lacks bones, and it is suitable for promotion as a children's food. A similar product, manufactured from other underutilized fish species, has recently been launched in Mexico by the national industry. This product, which retails for about 60 pesos/kg, is said to be well accepted and growing in demand.

Pepepez — a New, Frozen Minced Product

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Pepepez is a frozen, breaded product made from the minced flesh of fish by-catch. It was developed by Productos Pesqueros Mexicanos and is being produced on an industrial scale. The chemical composition, microbiological status, and physicochemical analysis of the product have been standardized. The product is now being produced in a plant at Tepepan, Xochimilco, and operations have been extended to fishing harbours on the Pacific coast and the Gulf of Mexico.

The main objective of the Pepepez project is to utilize the unmarketable but edible fish found in shrimp by-catch in new low-cost products for human consumption. In the past, the use of the by-catch was primarily for the production of fish meal. Industrial processing for direct human consumption was constrained by the great range of size, weight, and number of species within the catch.

However, mechanical flesh-and-bone separators increased the potential uses of the catch many fold. Mincing the fish has particular appeal in Mexico, where 46.2% of the population is younger than 14 years and many people do not eat fish, among other reasons, because of the fear of swallowing a bone. Annual per-person consumption of fish in Mexico is 8.8 lb. (4.02 kg) — the comparable figure for meat is 35 lb. (15.9 kg).

Productos Pesqueros Mexicanos (PPM) assumed the responsibility of developing a product that would increase fish consumption, especially among low-income groups. Its goal was to manufacture a product with a texture, taste, colour, and appearance acceptable to the consumers, a long shelf life, and an appropriate packaging.

Pepepez went through several stages: the formula was developed and market tested; production was undertaken in a pilot plant and evaluated; a large-scale plant designed; and the product marketed.

The two main sources for minced fish are the by-catch from trawling operations and the by-products from filleting of species that command high prices. The first is the most important and has been the key to Pepepez production. As the quality of the final product depends upon careful selection and handling of the raw material, only fresh or frozen fish have been used in this project.

During product development, researchers studied experiences from countries with a long history of fish processing, such as Japan, Sweden, and the United States. They integrated the information into the plans for the project to increase efficiency and control costs.

The two basic methods available for mechanical separation of flesh and bone render mince that is equivalent to more than 70% of the gutted, cleaned raw material. The capacity of both processes ranges from 200 to 2500 kg/hour. Separation is a crucial step because it determines the organoleptic properties (colour, elasticity, and microbiological quality) of the product. The lower the temperature during separation and the lower the pressure of the fish flesh against the perforated drum, the better the results in terms of texture. The main factor affecting texture is the presence of soluble protein and inorganic salts that form a viscous elastic system in the mince. Texture has been improved by the addition of agglutinating substances and salts. Washing has been introduced to the process to eliminate the pigment in the mince. At present, the water/mince ratio is 3 : 1, although research is being conducted into the use of a reducing agent to increase efficiency and save water.

A rotating screw press has proved to be more efficient in concentrating the mince than either a fine cloth sieve or a centrifuge. Flavours are added, and the product is moulded, frozen, and breaded. Research has indicated that better functional properties, as well as better colour, taste, and texture are obtained in products from mixed species.

The product comes in different shapes and in both breaded and unbreaded forms. Minced flesh and fish balls are also available. The ingredients, presentation, and labeling are standardized. Chemical, physicochemical, microbiological, and organoleptic qualities are also controlled. Chemical composition is moisture 55.0–70.0%; fat 0.1–9.0%; protein 13.0–20.0%; ash up to 1.0%; and carbohydrates up to 2.0% for unbreaded and up to 9.0% for breaded products. Peroxyde contents are no higher than 1 mEq; the pH is no higher than 7.0; and nitrogenated volatile base no higher than 30.0 mg N/100 g. The total count of microorganisms is not to exceed 1×10^6/g, and the coliform count is no more than 1×10^2/g; fungi and yeasts are not to exceed 5×10^2/g, and material containing *E. coli* or pathogenic organisms is rejected.

The taste, flavour, odour, and colour conform to a frozen standard, replaced every 3 months. The frozen product is fried in corn oil at about 150°C for 4–5 minutes on each side.

The manufactured product is packaged in polypropylene bags and thermosealed with low-density polyethylene; each 0.5-kg package includes a white, rigid, 6-mm thick polyurethane tray. The bags are packed in corrugated cardboard boxes (having a strength of 14 kg/cm^2) with a capacity of 20 bags each.

So far, Pepepez has demonstrated that minced flesh from species of fish of low commercial value can be used in the manufacture of a product having a high-protein content and good organoleptic properties at a price (cost/g protein) less than any semiprocessed meat available in the domestic market.

In addition, studies at PPM have shown that dark-fleshed species should be washed, then mixed, in a proportion of 40–50%, with white fish mince, which does not have to be washed. In general, minced flesh from species high in fat content is dark and, when washed, loses from 14% to 19% in weight (fat, organic matter, soluble protein, and salts). A handbook has been produced; it includes information on minces from flesh of different species so that methods of handling and proportions of mixed minces can be standardized.

White, lean species longer than 20 cm give the highest percentage (70) return from raw material; however, the efficiency of processing as well as the quality of the product depends on careful control of temperature and pressure in flesh-and-bone separation. The optimum temperatures for the process were found to be 6°C for the product and 10°C for the environment.

Microbiological analyses of the manufactured products showed widely different total bacteria and coliform counts, but the marketed products conformed to the standards. Both frozen, uncooked and control samples were used for the analyses.

Conclusions

The firm in charge of marketing and distribution of the product estimated that sales could reach 9091 t during the first year, just in the 35 cities where marketing structures are already available. The population in these cities represents 70.5% of the urban population and 39.7% of the total population.

Sales could increase 13.3% if distribution were extended from 35 to 54 cities. An estimated 10 249 t could then be marketed.

The finding that washing and mixing different minces can improve their colour and texture means that a great variety of currently unmarketable species can be used as raw material. In general, products from deboned, white flesh show the highest potential.

Pepepez is just the beginning of a program aimed at increasing fish consumption, making better use of fish resources in Mexico, and contributing to food self-sufficiency. In September 1979, a plant at Tepepan, Xochimilco, was opened, and, later, operations were extended to fishing harbours on the Pacific coast and the Gulf of Mexico.

Not all shrimp by-catch is suitable for use in food products. The PPM experience is that fish longer than 14 cm, are the most suitable, especially if they have been harvested in the last catches of a fishing trip.

At present, partial delivery of the by-catch to processing plants is provided for in the legislation regulating shrimp trawling. In the opinion of staff at PPM, this is the best way to encourage further exploitation of this valuable, but previously wasted, natural resource. The promotion of research and use of the by-catch is fundamental to the country's progress.

Fish Silage from By-Catch

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Small fish in the by-catch and by-products from industrial processing of fish (heading, gutting, and mechanical deboning) have been used in the production of fish silage — by the addition of 2.5% (by volume) of formic acid at ITESM. The product has been tested in diets of pigs in nearby swine-raising farms. Experimental biologic tests have shown that pigs receiving the diets have higher growth rates and better feed conversion efficiencies than do pigs fed fish meal. Results were especially encouraging for a dry mixture of silage and cereal, which was fed to suckling pigs.

The great diversity of species and available volumes of by-catch make it an attractive source for the production of acid-hydrolyzed products (fish silage). The process is not new. It was developed in the Scandinavian countries during the 1920s. Poland and Denmark produce fish silage on an industrial scale for livestock feeds. In recent years, the production of fish silage using by-products from the processing of tuna (Jones 1976, unpublished data) and white fish (Tatterson and Windsor 1974) has attracted much attention.

In the manufacture of fish silage, the raw material is ground so that the proteolytic enzymes in the intestinal tract and skin are spread throughout. Adding acid lowers the pH of the mixture, promotes enzymatic breakdown of protein, and prevents bacterial decay.

This process has been used at ITESM to convert shrimp by-catch to silage, and the product has been tested in diets of pigs. By-catch unloaded at Guaymas Harbour was used. In most instances, the raw material had been stored on the vessels' decks in plastic ice-filled boxes, or in refrigerated holds, for 6–12 hours.

The preparation of silage from finfish was straightforward (addition of 98.5% formic acid at 2.5% by volume). At 2% formic acid, the samples decayed within the first 98 hours after processing. However, fish silage could be prepared with concentrations of formic acid as low as 1.5% if enough hydrochloric acid were added to lower initial pH to 3. It was not possible to produce fish silage from either the by-catch crustaceans or the elasmobranchs alone; however, mixtures of these with finfish kept well. In addition, fish wastes from heading, gutting, and deboning were suitable for inclusion in silage. In general, when enough acid is added in the preparation of fish silage, stored mixtures are quite stable (Crean et al. 1979).

An LFP 300 semiindustrial plant (BP Nutrition Ltd) was evaluated for the production of fish silage from the by-catch and wastes from heading, gutting, and cleaning. The material was processed in a 1-t container, a pump grinding and recirculating the mixture; 85% formic acid was automatically added to the mince until it constituted 3.0% of the mixture. The product was stored in plastic containers. This system worked well.

Differences in hydrolysis time and final consistency of the silage depend on temperature. In the LFP 300 plant, a perfectly liquid silage can be produced in 3–4 hours during the summer months when temperatures reach 30–40°C, whereas, during winter months, when temperatures drop to 16–20°C, hydrolysis takes up to 24 hours and silage is thicker.

The liquid silage was tested for chemical composition, storability, and efficiency as feed. It was also dried and mixed with cereals for tests with suckling pigs. The second product has the same advantages as all dried feeds: it is a more complete food, transportation costs are reduced, and handling on the farm is simplified.

The drying of mixtures of fish silage with cereals such as sorghum and corn in ratios as high as 1 : 1 (original weight) proved to be successful. The liquid silage was mixed with cereal, spread into thin layers on concrete trays, and sun dried to about 10% moisture. Drying ranged from 4 to 8 days, depending on the season.

Protein and fat content in the silage was 17.3–24.5% and 1.4–4.1%, respectively. After 7 months' storage, only minor changes could be detected in the chemical composition, and the essential amino acids were well represented.

Biologic Tests

A series of tests were undertaken to determine the value of fish silage as a protein supplement in swine feed, in both prestarter and fattening stages.

In the first test, conducted in Guaymas, finishing swine were used. Fish silage used in this test was manufactured only from by-catch finfish; 85% formic acid was added to make up 3.0% of the volume of mince. The mixture was stirred regularly by hand for the first 24 hours. After 4 days' storage, during which it was stirred occasionally, the silage was poured into plastic containers and transported to the site of the experiment. Tests for growth rate were based on diets that incorporated fish silage as 5%, 10%, and 15% of weight. Fish meal was added to the control diet to ensure an equivalent level of fish protein. Sorghum, soybean meal, wheat germ, phosphoric rock, calcium orthophosphate, and salt were added. A commercial vitamin–mineral premix was also added. In this experiment, 40 swine, averaging about 20 kg each, were used. Animals were divided by sex and weight into eight groups, fed once a day, and weighed once a week. The test went on until every animal reached 90 kg (slaughter weight).

In this test, the inclusion of fish silage in the diets of the pigs clearly affected growth rates. Rates of live-weight gain were higher among all swine receiving the three diets to which fish silage had been added ($P < 0.05$) than among those fed the control diet. The feed-conversion efficiency increased with amount of fish silage added (Table 1). However, the differences in weight gain at the three levels of silage were not significant, nor was sex a determining factor. Odour and taste of the meat from these animals were not altered by the addition of fish silage, as shown by sensory tests.

In a subsequent test, dehydrated samples of a silage–sorghum mixture were used as a source of protein to supplement prestarter diets for suckling pigs. (Drying the product increases protein concentration and is essential for pigs at this stage.) The silage was prepared in the LFP 300 plant. It was poured on concrete trays, mixed with ground sorghum (1 : 1) to form a thin layer, and sun dried for a few days.

Two diets were used: the control diet, identical to that used on swine-raising farms in this region (basically sorghum, soybean meal, calcium, phosphorus, and a commercial vitamin–mineral premix) and an experimental diet in which 67% of total protein was supplied by a sorghum–silage mixture. The remainder was soybean meal, calcium, phosphorus, and the vitamin–mineral premix. Both diets contained 22.0% protein and had equivalent usable energy, lysine, methionine, calcium, phosphorus, and salt. A total of 40 Hampshire pigs were used (20 boars and 20 sows), each having an average initial weight of 4.75 kg. Animals were divided by sex and weight into four groups; water and food were supplied ad libitum. Animals were weighed once a week and amount of feed consumed was recorded. The experiment lasted 6 weeks.

No significant differences were found in live-weight gain from the two diets. However, sharp differences were found in amount of

Table 1. Growth, food consumption, and feed-conversion efficiency of finishing swine fed silage supplements.

	Silage (% of diet)			
Parameter	0	5	10	15
Average initial group weight (kg)	21.2	21.9	21.5	21.4
Average final group weight (kg)	94.3 ± 7.6	97.3 ± 10.1	95.0 ± 7.9	94.5 ± 11.0
Daily weight gain (g)	519 ± 54	603 ± 81.5	615 ± 6.7	615 ± 93.1
Food consumption (kg, dry weight)	298.2	282.0	265.3	249.3
Feed-conversion efficiency (kg live-weight gain/kg food)	0.245	0.270	0.280	0.293

Table 2. Growth, food consumption, and feed-conversion efficiency of suckling pigs fed silage supplements.

Parameter	Control		Experimental	
	Male	Female	Male	Female
Average initial group weight (kg)	5.1 ± 0.91	4.15 ± 0.47	4.05 ± 0.36	5.60 ± 0.96
Average final group weight (kg)	12.75 ± 3.88	11.60 ± 1.79	8.45 ± 2.40	16.60 ± 3.26
Daily weight gain (g)	184.5 ± 86.9	172.6 ± 30.4	104.7 ± 50.7	261.8 ± 86.7
Food consumption (kg, dry weight)[a]	403		358	
Feed-conversion efficiency (kg live-weight gain/kg food)[a]	0.377		0.430	

[a]Data recorded without regard to sex.

food consumed and, thus, in conversion efficiency, which was significantly higher in boars receiving the experimental diet (Table 2).

The sows receiving a diet to which fish silage had been added showed the highest live-weight gain of the four groups. Live-weight gain of boars receiving the experimental diet was the lowest of the four groups. The low growth rate of boars may have been caused by age differences, as this was the youngest group. They were probably too young to use feed efficiently. Also, there are always some pig litters that show a lag in growth.

Silage produced from the finfish portion of by-catch is an effective supplement to animal feeds. Although it is not possible to manufacture fish silage solely from the crustacean or elasmobranch portion of the catch, satisfactory results can be obtained when these groups are mixed in proportions less than 50% with finfish. Also good-quality silage can be prepared from by-products from the manufacture of fish products for human consumption (i.e., fish heads, viscera, and bones).

Dried with cereals, the silage can increase the protein content (per unit of weight) of animal feed, and the resulting mixture is suitable for use in the diets of suckling pigs. In tests at Guaymas, growth rates were equal to, or higher than, those usually obtained with diets common in the region.

Marketing, Economic, and Resource-Management Aspects

Possibilities of Marketing Shrimp By-Catch in Central America

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By-catch in the eastern Pacific mainly comprises species of high consumer demand. If they were fully utilized and the marketing of titi shrimp were modified, profits would increase noticeably. The economic advantages to be derived from a more rational use of these species and the creation of new markets are analyzed in this paper from data gathered during fishing trips made in February and March 1979. As the possibilities and problems are common to all countries in the area, a regional plan to coordinate joint efforts is advocated.

Study aboard shrimp trawlers in Panama Bay during February and March 1979 showed that shrimp by-catch in the Pacific territorial waters of Nicaragua, Panama, and Colombia comprises species of fish of high consumer demand in international markets. If these species were fully utilized, revenues would increase substantially. Data used in this paper come from trawling operations in which I was involved, classifying and weighing fish from three zones in the Panama Bay and determining their marketability.

A study was launched to determine composition and volume of by-catch, which was to be followed by marketing analyses and research on preservation techniques on board, in order to assess profitability of exporting these species. Although only the first stage has been completed, a glimpse of possible future profits can be had if one looks at retail prices and transportation costs.

The term "shrimp by-catch" has been used in this paper to mean species other than white, red, or carabali shrimps that are considered large enough to be kept by the shrimpers. Thus, some species of shrimp (e.g., titi, fidel), easily marketable abroad, come under this definition of by-catch.

Methods

A form was prepared for records of number of species, size, weight, and relative volume. Fishing trips were of 3–4 days — too short a time to allow shrimping far from the coast. The crews did not consider the areas to be the best shrimping grounds so the results of my study may not reflect the true picture of by-catch in the area. In fact, the species (e.g., surmullet) of interest thrive also in areas where shrimp trawlers do not normally operate.

Normal trawling operations were carried out, i.e., a zone was abandoned when the test trawl did not detect any shrimp or where titi shrimp prevailed over white; average duration was 2–3 hours and trawls were repeated when the catch proved satisfactory. Seven fishing trips were made, three in February and four in March, for a total of 22 days at sea; 75 castings were made, and the trawls were in operation for a total of 214 hours.

Observations

The crews

Among the many factors involved in the possible utilization of the by-catch, trawler crews are the most important. Their attitude toward landing the fish catch, their training, salary system, and potential income increases, etc. are at present unknown but are crucial. The shrimp-trawling activities have been geared to the demand for shrimp tails in the American market, so even the condition of the whole shrimp is not a concern.

Present use of the by-catch

The by-catch in the area can be divided into two categories: marketable fish and species that require special processing on board or ashore. I do not deal with the latter group in this paper. The former comprises fish potentially marketable abroad and species popular in the domestic market.

Almost all the fish marketable abroad are jettisoned to the sea, because either their value is not realized by the crew (e.g., different varieties of sole) or there is some uncertainty of demand. The species popular in the domestic market are not systematically thrown overboard. Rather, the last few days' catch is kept: a part is sold to intermediaries and the rest is taken home by the crew. When a vessel will be operating in an area for some time, these species are used as barter with merchants ashore. The crew always know someone who will exchange fish (and, apparently, also shrimp) for a number of different products (i.e., groceries, tobacco, lottery tickets, etc.).

The large amounts of titi shrimp jettisoned to the sea have begun to attract considerable attention. During the second trip alone, I saw hundreds of kilograms of yellow titi shrimp thrown overboard simply because they were smaller than average, although their quality — firmness and taste — was quite acceptable. Also, during the last trip, considerable amounts of titi shrimp of acceptable size were thrown overboard because either the catch was "tired" as a result of excessively long trawls (4 hours) or the volume caught was so large that the time between the landing of the twin trawls was insufficient for proper handling of the whole catch.

The colour of titi shrimp, when alive, would render its marketing difficult in Europe; however, once it has been cooked, it closely resembles white shrimp. This fact, combined with its fairly good size and the existence of markets for whole shrimp, makes the species commercially attractive.

On-board selection operations

When the catch is unloaded on the deck, shrimp are either headed immediately or just separated from the fish and headed later. In either case, the fish considered valuable are put aside, for up to 2 hours, without even being hosed down. If more attention were paid to these fish from the outset, their quality would doubtlessly be enhanced. The fish should be washed and stored in the hold before the shrimp are headed because it would take only 5–10 minutes for a couple of workers to do. However, as the crews are used to paying attention only to shrimp, any additional tasks would have to be accompanied by direct salary increases.

Processing titi shrimp on board

The chronological order of operations on deck is sorting shrimp from by-catch and discarding waste, heading white shrimp, and heading titi shrimp. However, the time spent on heading titi shrimp is the longest, followed by sorting catch and discarding waste.

That is to say, the product of lower market value is the most time-consuming (on board) and also the most painstaking, involving squatting for hours and inflicting scratches and cuts on the crews' hands. These findings apply only to average-size titi shrimp, for the smaller yellow titi shrimp are entirely jettisoned to the sea.

Tests conducted with small titi shrimp were encouraging, indicating that an easily marketable product similar to European-depth shrimp could be obtained if the shrimp were boiled and coloured artificially. This process could be undertaken on board, as is done on many European vessels. The crew would welcome a shift from the method of heading to boiling, as it would lighten their work load markedly.

Underutilized Species of Fish

There are some potentially marketable species in the different fishing zones. In my opinion, the most important are catfish, cachaco, small mackerel, and croaker, although squid, sole, plaice, and surmullet are also included.

In some countries, among them Nicaragua, attempts have been made to export catfish to the USA; however, they have not been successful, perhaps because the quality of the shipments is not uniform nor is the supply constant. In contrast, the problem with cachaco is merchandising. As with titi shrimp, if this fish were a different colour, it could be easily sold in Europe at a good price. All mackerel and croaker less than 25 cm long are routinely discarded. This fact is almost inconceivable, as these are two of the most popular and sought-after species in the domestic markets.

During the fishing trips, all of the underutilized species were tasted and were highly rated by national and foreign personnel, who included people from different social strata. After having tasted boiled surmullet, sole, squid, and titi shrimp, I feel that European consumers would find them quite acceptable.

The countries to which the fish are most likely to be exported are Spain, France, Italy, Germany, and England.

Conclusions and Recommendations

During the fishing trips I took in 1979, my observation was that the by-catch in Panama Bay potentially has a high market value and could command a good selling price if commercially exploited. The composition of the catch in other countries of the area, including Nicaragua and Colombia, is almost identical, although relative percentages are unknown.

Economic incentives for the crew to bring in the catch are fundamental; in the case of titi shrimp, the introduction of a new, simpler method of handling — boiling rather than heading — may be enough incentive to encourage shrimpers to explore the potential for the species.

If working procedures were modified and simple fish-handling methods were introduced, most, if not all, the marketable species could be kept on the vessels (both those with ice-filled tanks and those with refrigeration equipment) for the short (3–4 day) trips.

In the three countries in the area where it has been shown that most species in the by-catch are in demand on international and domestic markets, it is strongly recommended that at least one shrimp vessel be used solely for the by-catch (in some instances, there are government-owned vessels). These vessels would initially be a "test bench" for the modifications to be introduced and, later, (when the method has been perfected) be used as schools for the training of new crews.

As the by-catch in the region is quite similar, a regional plan is strongly recommended, making use of the Panamanian experience. This would make a collective approach possible, thus reducing the costs of the program.

It is vital for the shrimp industry in this area to open new markets, avoiding total dependence on the U.S. New markets would not only mean increased demand but, in some cases, higher prices — e.g., for titi shrimp — and use of previously wasted fish.

Financial Projections for Industrial Production of Minced By-Catch Fish

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On the basis of technological and marketing studies, industrial designs for by-catch retrieval and processing were drawn up. Financial analyses of the industrial models indicated that the products could be competitively marketed at prices that allow an incentive to be offered to the fishermen to bring in the by-catch. The industries should thus be economically viable. These findings support plans to install pilot factories at Guaymas to demonstrate the commercial utilization of by-catch.

Previous studies of the ITESM/TPI program developed several techniques for processing by-catch fish and demonstrated market potential for the products. As a basis for possible commercialization of these projects, two distinct industrial models have been designed and financially evaluated (Street et al. 1980; Young and Marter 1981). Model I is an industrial profile for the processing of by-catch fish into a dried and salted, deboned product for human consumption, with waste material being converted into silage. Model II is a commercial-scale demonstration plant to process by-catch fish into frozen and canned products, as well as salted, dried mince and silage. Both industrial models would utilize 100% of the by-catch fish landed.

Model I

Model I was designed to process 2.4×10^3 t of fish annually into 3.8×10^2 t of dried fish cake and 1.35×10^3 t of wet silage. Fish are gutted by hand and mechanically deboned, the recovered mince being mixed with salt and pressed automatically into cakes. Waste material is fed to the silage plant.

Wet cakes are precooked at 100°C for 1 hour and then gently dried at 40°C. Drying is in a two-stage, continuous tunnel system incorporating a series of trucks containing the wet material. The first stage of this dryer (at 100°C) is isolated from the dehydration section. Suitable dryers are already being used in the food and chemical industry and require only minor modification. The entire processing plant would occupy about 3×10^3 m^2.

Establishment costs for the plant are projected to be 22.34 million pesos (1980 prices), although they would be lower if the operation were part of an existing fish-processing plant. Total annual operating costs amount to 7.5 million pesos.

The break-even selling price for dried, salted fish cakes under the most optimistic conditions — i.e., for a zero raw-material cost and a silage value competitive with those of other protein feeds (3000 pesos/t) — was projected to be 0.91 peso each. This amount assumes capital borrowed at 16%. The price would be 1.64 pesos if the opportunity cost of capital were 24%. At a raw-material cost of 6000 pesos/t, which would provide a realistic incentive to the shrimpers, the cakes would be sold for 2.57 pesos each if interest rates were 16% or at 2.75 pesos each if interest rates were 24%. These prices are based on a unit weight for the cakes of 45 g, containing about 22 g protein.

Model II

Processing in model II includes flesh-and-bone separation systems identical to those of model I. In this model, however, the annual input of 2.4×10^3 t fish would yield 138 t dried, salted mince; 388 t frozen, breaded sticks; and 459 t canned fish picadillo (or 514 t canned fish sausage or 514 t canned fish pâté); and 1323 t fish silage. Full details concerning building requirements, handling, equipment specifications, and resource use have been provided elsewhere (Young and Marter 1981).

Total establishment costs for this model are about 26 million pesos (1981 prices). Drying, salting, freezing, and ensiling are the least

Dried, salted fish cakes, which are here being removed from the mechanical dryer, are integral components of both industrial models.

expensive processes to install and operate. Canning is more costly, particularly because the cans represent a major operating cost, accounting for 62–80% of the total cost of consumable goods.

This model offers an opportunity to operate different combinations of processes. The financial analysis, therefore, was designed to indicate the break-even product prices for various mixes of processing lines, with adjustments for optional cost sharing of equipment and other items. The joint options selected were:

- Two lines producing dried, salted fish

cakes and one line producing frozen fish sticks;
- One line each for fish cakes, fish sticks, and canned picadillo;
- One line each for fish cakes, fish sticks, and canned fish sausage;
- One line each for fish cakes, fish sticks, and canned fish pâté; and
- One line each for fish cakes, fish sticks, and all three canned products.

The first option can be established and operated at the lowest cost; the combinations of three products — dried fish cakes, frozen fish sticks, and one canned item — are intermediate; and the final option requires the highest expenditure but has the greatest flexibility in end-product output. Both capital and operating costs for combined options are only marginally lower than the total cost of individual product lines. Thus, opportunities for sharing of equipment and consumable items are relatively few.

Break-even product prices for model II were calculated to be: salted fish cakes 51 pesos/kg; frozen fish sticks 22 pesos/kg; canned picadillo 25 pesos/kg; canned pâté 26 pesos/kg; and canned sausage 33 pesos/kg.

The raw-material cost is taken to be 3000 pesos/t. When raw material costs change from 3000 pesos/t to 5000 pesos/t, fish-cake prices rise by 22.5%, frozen fish stick prices by 18.6%, and canned product prices by 9.3–14%.

Product Pricing and Market Potential

When raw-material costs are 5000–6000 pesos/t, break-even prices for dried, salted fish cakes for model I and model II are 56.5 pesos/kg and 62.5 pesos/kg respectively. At these prices, with allowances for distribution costs and profit, fish cakes would be extremely competitive with other animal-protein foods in Mexico. In particular, the low price of cakes per unit of protein is an important consideration for institutional markets. The prices of the products manufactured by the model-II system also compare favourably with current (July 1981) retail prices for equivalent, local food items. At an exfactory price of 2000–3000 pesos/t (or 17–19 pesos/kg protein), the silage by-product is competitive with alternative livestock rations available in the region.

Recently, the market for by-catch products has been further evaluated in an attempt to fix appropriate selling prices and to calculate the profitability of these industrial models. The data show a steadily increasing demand for dried, salted and frozen fishery products in Mexico. The market for canned products is less certain because of excess capacity for sardines and tuna. There is certainly a potential market for silage. Imports of animal feed are substantial, and livestock production is continually increasing. Feeding trials in the Guaymas region have effectively demonstrated the value of using by-catch silage in pig and poultry feeds.

This market information and the projected selling prices for the products indicate that these by-catch processing industries would be profitable. Moreover, the assumed raw-material prices would contribute an attractive revenue to the shrimping industry.

Project Implementation

The Mexican fisheries development bank (BANPESCA) undertook an independent evaluation of the model-I industrial design and approved its promotion to potential investors. The bank will act as a coinvestor or provide loan capital to private-sector investors and is optimistic that this venture will prove profitable, with scope for further development.

The model-II system will be implemented by the Dirección de Fomento Pesquero of the state government of Sonora. The project aims to attract potential investors by:
- Creating a model plant for alternative uses for by-catch;
- Manufacturing a range of products for wider market promotion; and
- Operating a viable self-financing plant to utilize by-catch for human food.

The financial evaluations on which the product costs provided in this paper are based were carried out by Peter Street and Alan Marter of the Marketing and Industrial Economics Section, Tropical Products Institute, London, England.

Optimization of Processing of Three Underutilized Fish Species

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*Spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogon undulatus*), and weakfish (*Cynoscion regalis*) are commonly found in the by-catch of shrimp operations in the waters off the coast of the southeastern United States. The economics of preparing these three species whole, deboned (minced), and filleted (both with and without the skin) are evaluated. The product yield for each stage of the process and the mechanical difficulties encountered are included. Results are expressed in diagrammatic form so that the product that maximizes profit for a given set of input–output prices is indicated.*

During the past few years, the Charleston Laboratory of the Southeast Fisheries Center has been investigating the mechanical processing of spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogon undulatus*), and weakfish, also known as gray seatrout (*Cynoscion regalis*). In the United States, these species are considered to be underutilized, although each is sought as part of a directed effort. For instance, croaker are caught as part of the mixed-species groundfish fishery for petfood in the Gulf of Mexico.

These three species are also an important part of the shrimp by-catch. Together, they compose more than 50% of the by-catch by weight in the Carolinas and Georgia. Spot accounts for roughly 39% of the by-catch in North Carolina, 40.2% in South Carolina, and 28.0% in Georgia. Croaker accounts for 24% by weight of the North Carolina by-catch, 9% of South Carolina's, and 21% of Georgia's. Weakfish accounts for 4%, 3%, and 7% of the by-catch, for North Carolina, South Carolina, and Georgia, respectively. The utilization of spot and croaker between 1973 and 1975 was less than 1% by weight of the by-catch in South Carolina and Georgia (Keiser 1977b).

When landed, these fish normally move through the marketing channels whole, and, only when they reach the retail market, are they headed and gutted or filleted. Exactly why this method of marketing has evolved is uncertain, but two reasons can be suggested. First, the low value and small size of the fish make hand processing uneconomic except for the retailer who can charge for the entire round weight of the fish and sometimes extra for processing. Second, purchasing whole fish is preferred by the customers so they can better judge the quality of the product (Pariser and Hammerle 1966).

We believe the economic feasibility of introducing mechanization into the processing of the three species deserves to be explored. Thus, we applied linear programing to laboratory data on yields from mechanical processing. The focus of the mathematical models was limited to fish preparation.

Experimental Procedures

Fresh fish packed in ice were obtained during 1979–81 from a commercial seafood dealer in North Carolina. For each of three sampling periods, about 68 kg of each species were obtained on the dock, iced, and transported to the Charleston Laboratory for processing. The fish had been harvested off the coast near Morehead City, North Carolina, 36–48 hours earlier. They were selected at random and represented the total catch.

The fish were graded by weight into various categories as a means to maximize efficiency in mechanical processing. Croaker were sized as small (<0.23 kg), medium (0.23–0.45 kg), and large (>0.45 kg); weakfish were sized as small (<0.34 kg) and medium (0.34–0.68 kg). Spot were not sized, as they averaged about 0.15 kg. The size ranges of the fish used in this work are not truly representative of the size ranges of these species as they are found in the South Carolina shrimp by-catch, where the average weight of the three species is: croaker 0.02 kg, spot 0.04 kg, and weakfish 0.02 kg (Keiser 1976). The differences in size occurred because the fish were purchased through commercial market channels. The analysis presented in this paper focuses on the fish that are larger than standard by-catch species and yet too small to merit a premium price in the market.

The yields were calculated as a percentage of the weight of the whole fish. The spot skinless fillets were skinned and filleted by hand, whereas we used mechanical equipment for all other processing (Fig. 1 and 2). The equipment comprised a Simard[1] scaler, Lapine machines for heading, gutting, and filleting, a Bibun flesh-and-bone separator, and an Arenco fillet skinner. The yields were determined by the weight of fish before and after each step (Table 1). Other equipment on the market may be more effective and can process larger fish than that used in this work.

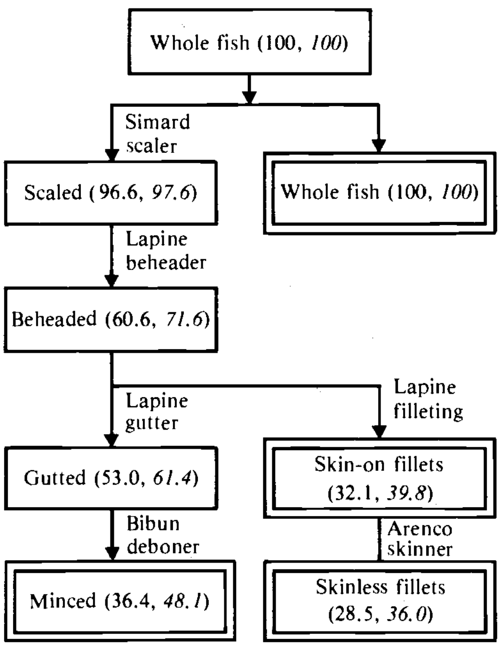

Fig. 1. *Processing of weakfish and croaker; yields appear in parentheses (those for weakfish are italicized). End-products are double boxed.*

[1]Use of trade names or products does not imply endorsement by the U.S. Department of Commerce.

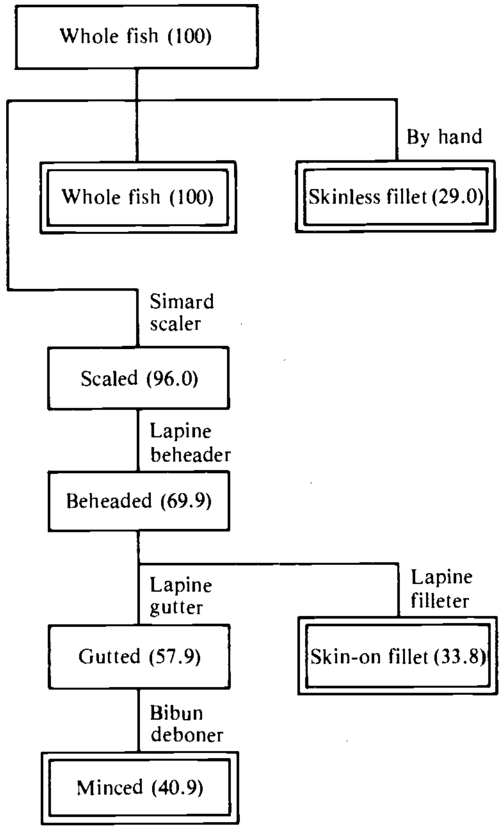

Fig. 2. *Processing of spot; yields appear in parentheses. End-products are double boxed.*

The equipment had been designed to process underutilized species indigenous to the southeastern United States. The scaler was designed to process fish weighing between 0.1 kg and about 1.4 kg and required only minimal adjustments to accommodate various-sized fish.

The beheader required only minor adjustments once it was set for a particular species, although configuration of the fish dictated positioning of the cutting blade to prevent excessive removal of flesh with the head. Variations in size of the fish seemed to make little difference in the beheader's performance. The maximum-sized fish it could handle was about a 1-kg croaker and a 1.4-kg weakfish.

The gutter was designed for fish from about 0.1 kg up to 1.4 kg. Some postprocess cleaning of the fish was required for removal of small amounts of viscera, kidney, and blood near the backbone.

Table 1. Processing yields (%) by species and size.

Species, size	Weight (kg)	Scaled	Headed	Gutted	Skin-on	Skinless	Minced
Weakfish							
Small	0.25	98.0	71.5	61.7	37.0	33.0	49.0
Medium	0.46	97.3	71.7	61.1	42.6	38.9	47.2
Average	0.35	97.6	71.6	61.4	39.8	36.0	48.1
Croaker							
Small	0.16	96.9	60.7	52.4	30.2	25.9	35.3
Medium	0.31	96.7	61.3	53.2	33.9	30.7	37.1
Large	0.61	96.1	59.1	53.2	32.2	29.0	36.9
Average	0.36	96.6	60.6	53.0	32.1	28.5	36.4
Spot	0.15	96.0	69.9	57.9	33.8	29.0[a]	39.2

[a]Cut by hand.

The filleter handled croaker up to about 0.45 kg and weakfish up to about 2 kg. Sizing of the fish within fairly narrow limits was necessary with the filleter because of its two vertical rotating blades that are adjusted to the width of the backbone. Even with readjustments for various-sized fish, the filleter did an incomplete job of removing the rib bones, and some hand trimming was necessary.

The fillet skinner did a poor job on soft-textured fillets but, when the fillets were chilled, complete removal of the skin without mutilation of the flesh was obtained.

The flesh-and-bone separator was not limited by the size of the fish and performed well. It was easy to clean and sanitize. Maintenance and breakdown were minimal under our light schedule of use.

Linear Programing Models

The three linear programing models developed for our analysis were based on the processing activities and do not include steps before processing (such as unloading the fishing vessels and sorting the fish) or after (such as packing and icing or freezing the product for shipment), even though these steps mean additional costs for the processor. Thus, the output prices used in the model represent a partial cost for the processor. Working backward from the wholesale price for the final market form, one would have to subtract these additional costs to determine the partial costs used in the models.

The linear programs chose the most profitable alternative, taking into consideration the product's yield, input requirements, and input and output prices. The programs do this by maximizing a linear equation for profit. Profit is a function of the level (amount) of a series of activities, such as selling mince or buying processing equipment time. The level of an activity multiplied by its unit revenue (or cost) determines its contribution to profit (Hillier and Lieberman 1974).

We assumed production costs to be $4.50/hour for machine-operator labour and $3.60/hour for hand labour. Trout is purchased for $0.99/kg exvessel, spot for $0.55/kg, and croaker for $0.88/kg. The machinery costs were calculated on a bond-financing basis at a 15% interest rate for 7 years. The yearly payment was divided by the number of days of operation — assumed to be 200. On the basis of these assumptions, the model determined the number of hours of daily use for each machine; the hourly costs were then determined and inserted into the model for the final estimation of costs.

The material-balance coefficients were experimentally determined; they indicated the weight of an intermediate product that would be used by a processing step to make 1 kg of its product. As an example, it takes 1.035 kg of whole croaker to make 1 kg of scaled rounds. We calculated this figure by taking the ratio of the percentage yield of the previous stage to that of the current stage (i.e., 100%/96.6% = 1.035). These coefficients were also multiplicative among the steps of a process. For example, it takes 1.886 kg of whole croaker to produce 1 kg of gutted rounds (i.e., 1.035 × 1.594 × 1.142 = 1.886, or 100%/53%).

The coefficients for machine and labour use were calculated from the manufacturers' specifications; they indicated the hours of machine or labour time necessary to produce 1 kg of product. The restrictions forced the amount of input purchased equal to the amount used. In scaling croaker, for example, the scaler was rated at 2400 fish/hour, so that in 1 hour 788 kg of scaled rounds could be produced (2400 fish × 0.34 kg/fish × 0.996 kg of scaled rounds per kg of whole fish). This would be 0.00127 hour/kg of product. The final restriction in the models limited the amount of whole fish purchased to 4545 kg/day.

Results

The results (Fig. 3) showed the range of output prices for which producing each of the products (whole fish, mince, and fillets) would maximize profits. They indicated that a profit can be made from producing a minced product or fillet but that more profit can be made from selling the fish whole when there is a market for that product form. For example, when whole weakfish can be sold for \$1.76/kg, the minced product must be sold for better than \$3.71/kg, or the skinless fillets must be sold for better than \$4.99/kg, to increase profits by producing these items.

However, the whole-fish selling price is relevant for the calculations of opportunity cost for the minced or filleted forms only as long as one can actually sell all of the available fish whole at this price. Because the opportunity cost represents the difference between using an input in the most profitable way and using it another way, it is equal to zero when there is a surplus of fish or when the fish are too small for the market. The relevant costs are then only the actual purchase price of the fish and the machinery and labour costs.

The cost of cutting the fish into fillets was calculated from the models, and the amount was shown to decrease markedly as the numbers of fish, processed per day, increased (Fig. 4). The reason is that machinery and cleanup-time costs are spread over the larger quantities of fish. The minimum level of daily output required to bring the cutting costs below

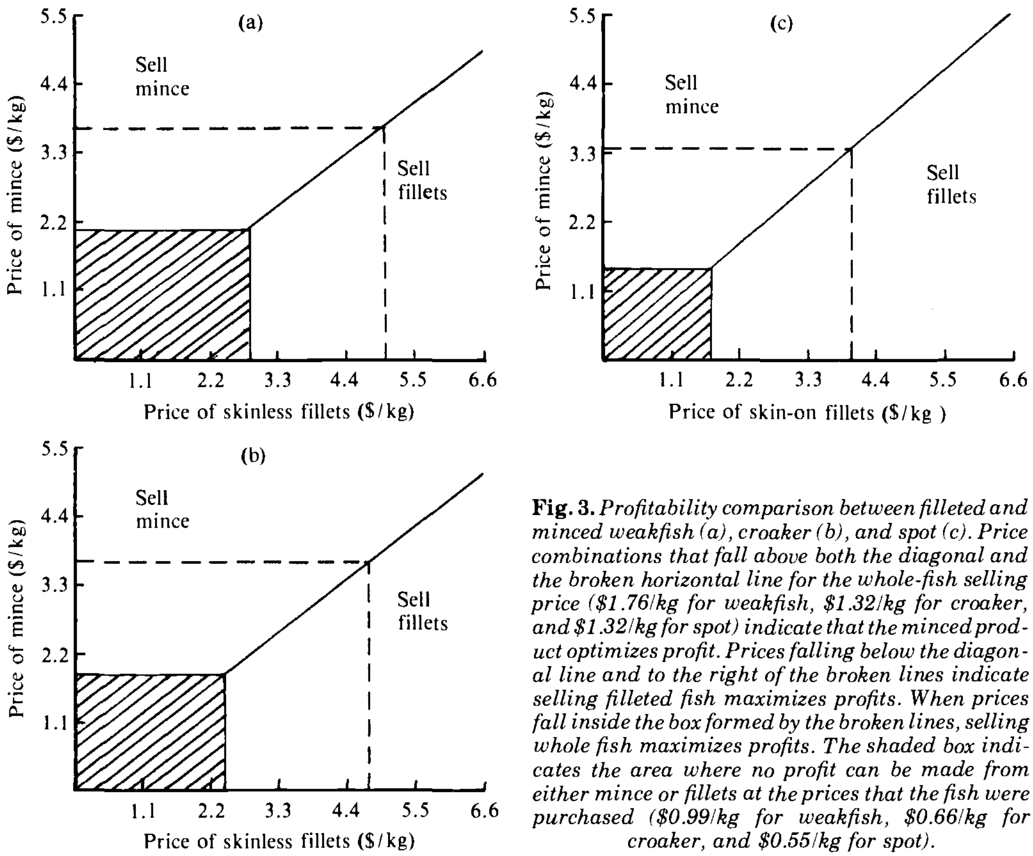

Fig. 3. *Profitability comparison between filleted and minced weakfish (a), croaker (b), and spot (c). Price combinations that fall above both the diagonal and the broken horizontal line for the whole-fish selling price (\$1.76/kg for weakfish, \$1.32/kg for croaker, and \$1.32/kg for spot) indicate that the minced product optimizes profit. Prices falling below the diagonal line and to the right of the broken lines indicate selling filleted fish maximizes profits. When prices fall inside the box formed by the broken lines, selling whole fish maximizes profits. The shaded box indicates the area where no profit can be made from either mince or fillets at the prices that the fish were purchased (\$0.99/kg for weakfish, \$0.66/kg for croaker, and \$0.55/kg for spot).*

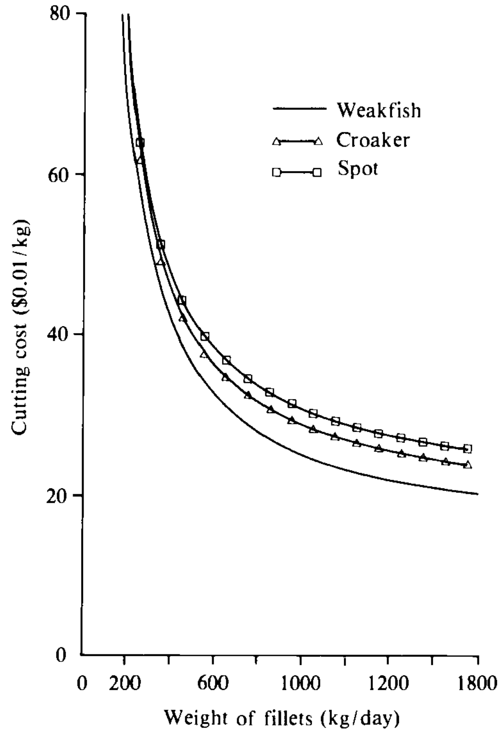

Fig. 4. *Cutting cost for weakfish and croaker skinless fillets and for spot skin-on fillets.*

that of a hand-cutting operation, can be determined from the results. For example, if hand cutting weakfish currently costs $0.30/kg, then at least 1000 kg/day of fillets would have to be produced to justify mechanization. The assumptions underlying the cutting-cost calculations were that machinery cleanup would take 8 person-hours/day; that 8 people would be working the processing line; and that labour costs would be $4.50/hour. Other assumptions were that equipment costs and the number of days of use would be the same as for calculations of process superiority. This approach assumed that the yields would be the same for both hand and machine filleting.

Two facts that have not been embraced by our models are that solid waste produced by mechanical processing of the fish is substantially larger than that incurred when fish are sold whole and that, in the filleting of fish, one has another attractive option — mechanically deboning the frames.

Discussion

We have shown that the mechanization of either filleting or mincing fish will be profitable if several conditions are met. First, there has to be a surplus of raw material, either because of overabundance or because the fish are too small for the whole-fish market. For the shrimp by-catch, this would normally be those fish larger than the minimum required by the machinery and smaller than the minimum for the market. The shrimper must also be able and willing to sort, hold, and land fish of this size. Second, there has to be a market for the product. Someone has to be willing to purchase a minced product or very small fillets made from one of these three species. To date, market acceptance has not been demonstrated for the products from these species. Third, the catch mix must be such that reasonably long production runs can be made without readjustment of the machinery. Fourth, these conditions must exist for a sufficient number of days of the year so that the capital costs of the machinery can be reasonably amortized.

We have not tried to define exact parameters for the above conditions, because they will vary greatly with locale. But we have chosen to outline them so that they can be examined when an investment decision is being considered. The technique of linear programing has been shown to be useful, when combined with experimental processing data, in the determination of the factors necessary to initiate a successfully mechanized facility for processing the shrimp by-catch.

Economic Profiles for Three Products Made from By-Catch

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Economic profiles for three minced products made from by-catch are presented. All three products — fish sticks, kamaboko (Japanese style), and fish paste or pâté — are suitable for the white-fleshed fish found in the by-catch and already have established markets.

Newly developed flesh-and-bone separators provide a potential means to utilize by-catch for human consumption. The fish must be headed and gutted by hand or mechanically and cleaned carefully so that all the blood, viscera, etc. are removed. They can then be minced or chopped mechanically into pieces (maximum 5 mm). The flesh-and-bone separators remove the scales and bone from the mince, and the processing is completed in a strainer, which eliminates hard pieces more than 1.5–2 mm in diameter.

If the flesh is not white, it must be bleached in fresh water at low temperatures (below 20°C) and then pressed or centrifuged. The minced white flesh is mixed with salt, starch, condiments, and spices — such as onion, ginger, garlic, nutmeg, allspice, curry powder, etc. Finally, it is shaped according to market requirements.

The mince can be breaded, i.e., covered with flour, dipped in egg, and covered with bread crumbs. This is the approach in the production of fish sticks. The addition of 10–15% shark flesh (ground well) to the mince increases elasticity and yields a substitute for kamaboko, a traditional Japanese food item. Another use for mince is fish paste or pâté. In this product, the headed, gutted, and cleaned fish are cooked at 115°C under pressure (0.5–0.7 kg/cm^2) for 90 minutes and then processed as for the other two products. The dehydrated flesh is cooked with vegetable oil, mixed with condiments, and mashed in a colloid mill. The colloid mill produces a fine fish paste that can be packed in a pouch or canned. It must be sterilized at 110°C. The yield depends on the size and the species of fish, but a general estimate for all three processes is 38–45%. The basic equipment required is similar for the operations. The investments needed range from about U.S. $350 000 to $4.1 million (Table 1). The difference primarily reflects the much larger operation envisaged for fish paste (two full processing lines).

Table 1. Economic profiles (U.S. $) for production of three minced foods from the by-catch.

	Fish sticks	Kamaboko	Fish paste
Packing			
Primary	1-lb trays	½-lb bags	½-lb retort pouches
Master cartons (lb)	50	50	25
Plant capacity (t/year)	1100	660	5000
Annual production	492 t/year	343 t/year	20.68 million pouches
Market	Local; USA; Europe	Central America; Colombia	Local; USA; Europe
Employment (persons)	7	25	102
Costs ($/lb)	0.473	0.704	0.355
Expected exfactory price ($/lb)	0.550	0.800	0.400
Expected annual profit ($)	72600	72500	930600
Profitability (%)	21.7	15.8	22.6
Break-even point (t/year)	269	193.5	2566

	Specifications	Amount ($000)	Specifications	Amount ($000)	Specifications	Amount ($000)
Investment		**334.7**		**457.7**		**4115.0**
Building ($300/m^2)		40.0		70.0		400.0
Mixing machine, colloid mills, etc.		–		–	2 processing lines	1550.0
Fish-washing machine	500 kg/hour	20.0	50-60 kg/hour	4.9		–
Bleaching machine	2500 kg/6-8 hours	42.0	1500 kg/6-8 hours	36.9		–
Screw press	300-400 kg/hour	28.0	100-200 kg/hour	20.0		–

(Table 1 continued)

(Table 1 concluded)

Meat chopper (1500 kg)		4.9		4.9		–
Strainer (500-1000 kg/hour)		5.6		5.6		–
Grinding machine (50-60 kg/hour)		–	3 units	33.9		–
Silent cutter (300-350 kg/hour)		32.2	3 units	96.6		–
Steam boiler		–		–		245.0[a]
Transport facilities		–		–		140.0
Bone separator, middle type		5.6		–		–
Band saw		2.0		–		–
Steaming box		–	30-40 kg	8.2		–
Meat separator, middle type		–		11.4		–
Boiler		–		35.0		–
Frying machine		11.5		11.5		–
Forming machine		–		8.5		–
Freezing		–		–	375 t, 10 t/day	450.0
Cold-storage room (−18°C)	15 t	22.0	10 t	15.5		–
Freezer (−35°C)	2 t/day	40.0		–		–
Office equipment		3.0		30.0		–
Miscellaneous (5%)	of $256800	12.9	of $365900	18.3	of $2785000	140.0
Working capital (20% of variable)		65.0		73.4		1190.0
Variable costs		**324.7**		**367.5**		**5952.0**
Ingredients						
By-catch (@ $100/t)		110.0		66.0		500.0
All additives		39.9[b]	@ $25/t	16.5		596.3[c]
Vegetable oil (@ $950/t)		–		122.0		1900.0
Processing						
Water (@ $0.3276)		1.9		1.1		170.5
Electricity (@ $0.08/kwh)		6.9		5.4		131.2
Fuel		–	@ $1.36/gal	2.7	@ $220.50/t	185.2
Refrigeration oil		–		–		7.8
Packing materials						
Individual	@ $0.0025 + 1%	23.9	@ $0.03 + 1%	45.8	@ $0.02 + 1%	423.6
Carton (@ $0.803 + 1%)		15.4		12.3		335.5
Labour						
Workers (@ $240/month, 13 months)		62.4		78.0		287.0
Professionals (@ 750/month)		48.8		–		97.5
Miscellaneous (5%)	of $309200	15.5	of $350000	17.5	of $5668600	283.3
Fixed costs		**121.9**		**163.9**		**1387.1**
Repair and maintenance						
Building (2.5%)		1.0		1.8		10.0
Equipment (5%)		11.5		14.8		119.3
Depreciation						
Building (5%)		2.0		3.5		20.0
Equipment (15%)		34.5		44.4		357.8
Interest (18% of investment)		60.3		82.4		740.7
Insurance (2.5%)	of $269700	6.8	of $365900	9.2	of $2925000	73.2
Miscellaneous (5%)	of $116100	5.8	of $155400	7.8	of $1321000	66.1

[a]Includes transformer station power supply, telephone, telex.
[b]Composed of wheat flour @ $600/t ($52000), bread crumbs @ $1000/t ($10700), egg soup @ $2000/t ($8500), salt, pepper, etc. @ $900/t ($15500).
[c]Composed of salt @ $63/t ($6300), pepper @ $2500/t ($187500), spices @ $1500/t ($102500), tomato concentrate @ $750/t ($150000), sodium cascinate @ $750/t ($150000).

Management of Shrimp Fisheries

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One of the resource-management options for countries in the Western–Central Atlantic Fisheries Commission (WECAFC) is to limit fishing effort in shrimp fisheries at times when by-catch constitutes a large portion of total catch. This would make good economic sense from the point of view of the shrimp industry (yields would not decline substantially and profitability would increase) and from the point of view of the groundfish industry (more commercial species would survive to marketable size). Controls on the time as well as the areas of open season are a first step. Other options, such as the development of gear that allows juvenile fish to escape, require considerable additional research. In the meantime, efforts to land and use the by-catch, now being discarded at sea, should be encouraged.

The question of improving utilization of shrimp by-catch has been addressed repeatedly, but few practical measures to estimate wastage or to improve use have been carried out. Only a portion of the by-catch consists of commercial species, and most of these are small — 20 cm or less.[1] Estimates of the actual percentage of commercial species in the catch are not readily available, but there are some indications that the proportion used is between 8% and 10% of the total catch. For example, although Young (1979e) reported by-catch/shrimp ratios of 3 : 1, 13 : 1, and 15 : 1 for Colombia, Costa Rica, and Guyana, respectively, Martínez (1979) noted that marketable by-catch/shrimp ratios for these areas were 1.1 : 1, 0.1 : 1, and 5.9 : 1. One may hypothesize, however, that a large proportion of the unused species consists of potentially commercial but undersized fish.

FAO figures for overall landings of all species of shrimp in its statistical area 31 were 182 230 t in 1980. Although the by-catch/shrimp ratios vary widely between 1 : 2 and 1 : 19, the unweighted average for all areas and all fisheries is roughly 1 : 8. If one assumes that most by-catch species brought on deck are discarded dead (and this is the usual observation for northern species, even if it has not been tested explicitly in the WECAFC area), the waste for statistical area 31 is phenomenal — an estimated 1.42×10^6 t. This figure should only be regarded as a gross, first estimate and depends heavily on the overall estimate of the by-catch/shrimp ratio. In theory, estimates of by-catch should be obtained for each fishery separately and then combined. Nonetheless, this figure establishes the potential order of magnitude of the resource being discarded. Because of the imprecision of existing information, it is impossible, at present, to say what the true cost of waste is in the shrimp fisheries of the WECAFC region, but the loss in potential yield is probably tens, or even hundreds, of millions of dollars. Cutting this loss (although impossible to eliminate completely) should receive priority in decision-making about management measures for the shrimp fishery. Not only is a significant potential revenue involved but also a valuable and largely underutilized source of protein.

I have made some gross calculations of the potential benefits, worldwide, from cutting the losses (Table 1), and because of the uncertainties, I have made some assumptions:

- That between 20% and 60% of the 1.415×10^6 t of discards are commercially valuable species;
- That between 10% and 30% of the biomass of potential by-catch species — if they had not been included in the by-catch — would have survived natural causes of death to be available later in a fishery directed specifically toward finfish;
- That these survivors would by then have increased their weight, on average, by 10-fold (commercial size); and
- That the value of commercial-sized fish is between U.S. $200/t and $600/t.

[1]There are markets for small individuals of commercial species in southern Europe and Asia that should be explored.

Table 1. Hypothetical benefits from 10–30% survival of commercial species (at 20%, 40%, and 60% of estimated total by-catch — 1.415×10^6 t) and sale at three possible prices.

Commercial species in by-catch (% by weight)	Commercial species in by-catch: Discards (t)[a]	Discards harvestable at commercial size (%)	Potential weight of harvest (t)[b]	Value of discards if harvested at commercial size: U.S.$/t	Value of discards if harvested at commercial size: U.S.$ million
20	141500	10	141500	200	28.3
				400	56.6
				600	84.9
		20	283000	200	56.6
				400	113.2
				600	169.8
		30	424500	200	84.9
				400	169.8
				600	254.7
40	424500	10	424500	200	84.9
				400	169.8
				600	254.7
		20	849000	200	169.8
				400	339.6
				600	509.4
		30	1272500	200	254.5
				400	509.0
				600	763.5
60	707500	10	707500	200	141.5
				400	283.0
				600	424.5
		20	1415000	200	283.0
				400	566.0
				600	849.0
		30	2121500	200	424.3
				400	848.6
				600	1272.9

[a]This figure assumes 10% of by-catch is at present being used and, thus, is not part of the discards; thus, if 20% of the by-catch is commercial species, half this amount, or 1.415×10^5, is assumed to be used.
[b]This figure assumes 10-fold increase in weight for mature, commercial individuals.

The results indicate potential benefits of U.S. $28–1273 million, i.e., between 2% and 70% of the present value of the shrimp catch. Although these limits are unrealistic, the calculations suggest that, in addition to the objective of increasing percent use of by-catch species, the main thrust of new developments should be toward improving survival of commercial fish making up the by-catch.

One may approach this objective in four ways:

- Develop selective fishing gear to reduce the by-catch;
- Increase the mesh size of the gear;
- Close the fishery at times, and areas, where by-catch is high and shrimp-catch rate and mean shrimp size are low; and
- Control the intensity of fishing for shrimp to reduce incidental catches of fish.

The feasibility of the first three of these options depends largely on future research. For example, available studies on the selectivity of penaeid shrimp by different mesh sizes, carried out in West Africa, have suggested that few large shrimp escape mesh sizes up to 60 mm (stretched). This size mesh should release substantial numbers of small fish. However, selectivity experiments within the WECAFC region are needed to confirm these results and to determine the effects of larger mesh sizes, particularly on the yield of smaller, presently underexploited, species of shrimp, such as seabob. The fourth option could be implemented almost immediately.

Intensity of Exploitation

The rate of exploitation in most shrimp fisheries is extremely high (annual shrimp mortalities of $F = 2.0–3.0+$ have been recorded: equivalent to annual rates of removal of 95% or more). Although mortalities of marine fish stocks occupying the same grounds as the shrimp, and at least partially available to the same gear, are not likely to be so high (the gear selects for shrimp), they are unlikely to be negligible either.

Thus, high rates of exploitation are needed so that an unduly large proportion of the short-lived shrimp is not lost to harvesting through natural death. Although changes in the dominant shrimp species indicate that overfishing of some species is a possibility at high levels of effort, the short life span of shrimp suggests that, at moderately high fishing intensity, survivors will be sufficient to spawn and ensure stock replenishment. Probably the greatest source of variations in shrimp production is environmental fluctuations (e.g., river runoff, drainage of coastal nursery areas, etc.).

Changes in the amount of fishing effort in most of the shrimp fisheries in the region can be represented by a flat-topped yield curve, obtained from production-model analysis. This means that overall shrimp landings (although not necessarily the yields of individual species) increase rather rapidly to a maximum with fishing effort but show relatively little subsequent change with further increases in effort. In terms of the concept of *optimal fishing effort* (f_{opt}) defined either from an analysis of the economic and social conditions of the fishery at different levels of effort or by means of some internationally recognized approximation to it, such as $F_{0.1}$ (Fig. 1), the present fishing effort in most shrimp fisheries in the WECAFC region is too high.

The response of longer-lived finfish species

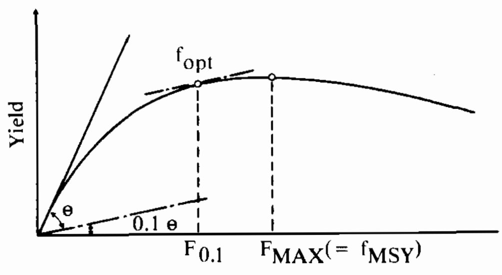

Fig. 1. *Method of calculating $F_{0.1}$ (one measure of "optimal fishing effort" f_{opt}) and its relationship to f_{MSY} (fishing at the maximum sustainable yield). At $F_{0.1}$, roughly nine-tenths of the MSY can be taken by only two-thirds of the effort (and cost of fishing).*

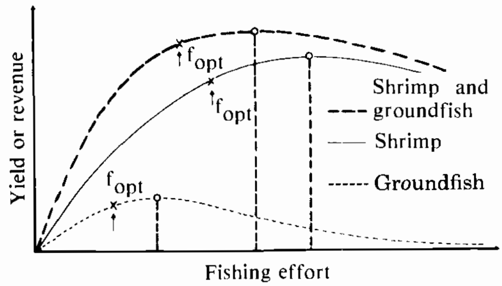

Fig. 2. *Levels of optimal fishing effort for shrimp, groundfish, and the combined fishery.*

to heavy exploitation is different. With increasing amounts of fishing effort, total yield first increases, reaches a maximum at some moderate level of fishing intensity, and then decreases as further effort is exerted. The fish yield at the present high rates of exploitation is much lower than the maximum yield of fish possible, not only because the mesh size is small but also because the high frequency of harvests removes young fish and, thus, a high proportion of the catch consists of juveniles (Fig. 2).

The combined-yield curve for shrimp plus fish has a maximum at a lower fishing intensity than does the curve for shrimp alone. Similarly, the value of f_{opt} is less. That is, if the effects on the finfish resources are taken into account, reducing the fishing effort for shrimp is more advantageous than it would be if one were considering the shrimp fishery alone.

The tentative conclusion from this kind of informed speculation is that, although increasing the shrimp-fishing effort beyond the level corresponding to f_{opt} as defined in economic terms is not necessarily going to reduce the overall shrimp catch (although it will reduce its profitability), it is likely to have a growing impact in reducing the potential economic yield from commercial species that figure in the by-catch. This conclusion and the provisional calculations provided to support it are merely intended to draw attention to the general lack of knowledge of the effects of intensive shrimping on the general fisheries productivity of an area and to provide a framework for future investigation.

Practical Measures

Experimental work and studies in the region have proved that no single solution is possible; local conditions and fishing systems play a great role in the salvage and utilization of by-catches. However, this matter is so important, the problems involved are so peculiar, and the ways to tackle them so different, that a specific and integrated project, separated from the WECAF Fisheries Development Programme[2], but in coordination with it, will be required if significant advances are to be made on the sustained recovery and commercial utilization of by-catches in the region. Systematic investigations on various technical alternatives for recovering and utilizing this raw material are required, and the proposed project should play a coordinating and catalytic role, working through national institutions and the industry in the countries of the region where shrimping is a major activity.

Five main activities emerge that could be supported by the Commission to cut the waste currently caused by shrimping operations:

- Fuller utilization of existing by-catch, such as is now being promoted by Guyana and Mexico;
- Research on the design of an effective and practical trawl that can reduce by-catch, especially of juvenile fish of commercial value in areas where a directed groundfish effort is either possible or existing;
- Study of mesh sizes used on shrimp trawls to determine the optimal mesh size for yield of shrimp and the impact on escapement of juvenile fish;
- Investigations of seasonal changes in by-catch/shrimp ratios, by-catch composition, and shrimp landings as a basis for development of management measures such as seasonal closures; and
- Examination of the overall management objectives of the shrimp fisheries, not just in terms of better definition of the economic optimum for the shrimp fishery but in terms of the potential impact of intensity of shrimp fishing on the survival of by-catch species to commercial size.

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[2]This is especially relevant now, as the WECAF project was terminated in December 1981 — subsequent to the writing of this paper — for lack of funds.

Regional and Country Developments

Fishery Development: the Latin American Model Revisited

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At the request of Latin American countries, the Inter-American Development Bank began financing fishery-development projects with the aim of improving and, where necessary, establishing the entire infrastructure for producing, processing, and marketing fish. The main reason that the IDB has moved in this direction is that it sees fishery development as offering the greatest potential for expanding protein sources for local populations. By-catch and aquaculture projects are receiving particular attention.

Twelve years ago, the Inter-American Development Bank (IDB) initiated a program to promote fishery development in Latin American countries. In 1980, the fishery production in these countries amounted to 9×10^6 t, with an overall landed value of about \$3 billion. An estimated 2 million persons are engaged in fishing activities; the majority are coastal fishing personnel whose annual rate of productivity averages 3 t/worker. Theoretically, the supply of fish in these countries is 28 kg/person, but the actual human consumption is about 8 kg/person. The difference, 20 kg, is either exported or processed for animal or industrial use. These figures do not include the losses due to the lack of infrastructure (30% of the total catch in some countries) or to inappropriate handling ($\sim$3–5 $\times 10^5$ t of shrimp by-catch).

It is estimated that Latin America has an annual animal-protein deficit of 2×10^6 t. This represents about 20×10^6 t of edible meat. Fish — probably the cheapest source of protein — is the one possible solution to this problem. If 25% of the protein deficit in Latin America were to be satisfied by fish products, an additional 5×10^6 t would have to be produced. This would require a 75% increase in regional fishery production and investments of about \$3 billion, but it would generate new employment opportunities for about 500 000 people.

The complexity and diversity of factors involved in the food-supply problem of developing nations make long-term projections difficult. Because the socioeconomic structure and the technological advances are essentially dynamic, no one can forecast the population growth or the migration trends from rural to urban areas, for the next 15 or 20 years. It is even more difficult to anticipate income levels, purchasing power, and individual preferences.

The development of food technology in the last decades has mainly focused on food production for high-income markets whose consumers normally eat more than they need. There are not enough well-equipped institutions dedicated to developing production techniques for unsophisticated foodstuffs destined for developing countries. Fishery development must be planned throughout all stages, with emphasis being given to low-cost techniques that maximize the use of local resources normally underutilized.

Latin America has an additional potential of 7–8 $\times 10^6$ t/year of unexploited marine resources. This amount only applies to species for which there exist reliable data that could help in projecting annual catch rates. It does not include species that are being evaluated (e.g., Antarctic krill) or resources that are being categorized (e.g., squid and octopus).

In addition to unexploited marine resources, aquaculture offers an opportunity for increasing production through diversification of agricultural activities, low-capital projects, high productivity, easy market access, self-supply of protein for isolated human settlements, etc. The problem encountered in the implementation of aquaculture-development policies is mainly of a managerial and operational nature. Latin America has but a few aquaculture experts and seriously needs additional extension personnel.[1] Land tenure is an obstacle for loans to small fish farmers because they frequently do not own land.

Objectives

Because Latin American countries have expressed an interest in fishery development, IDB is providing assistance to identify priority areas and to establish specific investment projects to be financed by international lending institutions.

One of the objectives is to promote integrated sectoral projects, e.g., port infrastructure, fishing fleets, processing plants, marketing systems, training centres, and research programs. The purpose is to eliminate the bottlenecks that would arise if boats did not have port facilities, processing plants, or marketing networks.

A second objective is to create, on the basis of the projects, new development-minded fisheries institutions. At present, the fishery administrations of most countries are nothing more than small scientific and statistical units.

Third, priority is given to projects with high socioeconomic impact. They normally encounter many difficulties, cannot be implemented rapidly, and are not attractive to the private sector. A case in point is the development of coastal artisanal fisheries to produce fish for local consumption.

Another objective is to design structures that could be used to expand the goals of a project by adding new investment outlets to the original framework. For example, integrated programs based on fishery cooperatives or on fishing industries could be expanded to incorporate new groups.

New production projects could be implemented either through cooperatives of coastal fishing personnel or through fishing companies. However, in some cases, they would have to be set up through state corporations, until the sector becomes stable enough for the participation of private investors.

Intermediate, labour-intensive technologies should be selected when feasible, so that resources are devoted to low-cost final products that can be made available to the majority of consumers.

[1]A regional training centre is starting operation in Brazil through an FAO/UNDP project and an IDB fellowship program.

Performance

By October 1981, IDB had promoted and financed 36 fishery-development projects and 40 technical-assistance programs. Twenty-one countries have benefited from these projects.

The fishery projects under way represent a total investment of U.S. $764 million and involve financing in the amount of $296 million. Projected production is 2.5×10^6 t/year, and this figure represents an increase of 100% in the regional supply of fish for human consumption.

One important side-effect of the projects has been the creation of development institutions. Independent executive bodies have been organized and are gradually acquiring managerial capacity for decision-making, although considerable time will elapse before they operate efficiently.

Because the fishing industry in many Latin American countries was at an incipient stage of development, the problem of dealing with established structures, vested interests, or complex political implications has not been a limiting factor. However, it does constitute a constraint in the sense that public and private support for fishing projects has been weak because of the lack of political priority for fishery projects within government plans. When problems — no matter how insignificant compared with those in other sectors — arise during the execution of a project, the authorities tend to become discouraged and are reluctant to pursue the task. A program of hemispheric scope, such as this one, involving a sector with little experience or tradition, is bound to have areas of weakness where mistakes are made. However, the mistakes will be increasingly fewer, as countries develop programs and expand their pool of skilled personnel.

The experience of IDB in supporting the development of the fishery sector in the vast continent of Latin America has indicated that development-financing agencies can make substantial contributions to the general progress of some new areas at regional levels. The main ingredients for an efficient policy are a global and accurate diagnosis about the problems and components of the sector, including natural and human resources, institutions, government policies, infrastructures, and production capacities; reasonable projections for development, divided in stages with specific targets; a flexible but aggressive policy for the achievement of the projected targets; the resources to offer convenient technical cooperation in strengthening the executing agencies; and a suitable monitoring system for both the follow-up of the project implementation and, later, the evaluation of results.

The past 30 years of fishery development in Latin America have shown that when there is a choice between moving ahead, even at the risk of unforeseen problems, and waiting until nearly perfect theoretical projects can be designed, one must go ahead. Unless the first step is taken, nothing will be done.

French Guiana

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At present, the by-catch that is landed in French Guiana amounts to about 150 t/year and comprises grounders, red snappers, flatfish, squids, crabs, and seatrout. If shrimpers were willing to land all these components of the by-catch, they could easily accommodate them on board and would at least double their landings. Another 9% of the by-catch is marketable and should be kept, but, because it constitutes about 3000–5000 t/year, landing it would necessitate changes in trawler management and design. The remainder of the by-catch is unlikely to receive much attention in French Guiana because there is no market for it.

At present, about 2000–3000 t/year of headed shrimp are brought to the Cayenne factory by a fleet of 86 trawlers (59 American, 22 Japanese, and 5 French vessels).

In 1977, the European Community issued new regulations to monitor the activities of foreign shrimp trawlers in coastal waters. Under the legislation, foreign trawlers are:

- Restricted to a definite number;
- Obliged to unload all shrimp catches at the French-owned factory; and
- Prohibited from trawling in shallow waters (<30 m deep) from May to October — a move to protect young shrimp (<14 cm long).

The management and use of shrimp catches have improved considerably since these regulations were implemented.

Thus far, no rules have been laid down, however, for the handling of the shrimp by-catch. At present, fishing companies land only a small quantity of by-catch — less than 150 t/year comprising exclusively grounders, red snappers, flatfish, squids, crabs, and some large seatrout. This means that a large portion of the by-catch is wasted.

French scientists have long recognized the need for regulations that govern by-catch, and, recently, they have been given an opportunity to collect the statistical data that would provide a basis for realistic controls. They are participating in a long series of scientific cruises on a Japanese shrimp trawler, and they are now in a position to assess the quantities of by-catch from shrimping operations in high-yielding waters (30–65 m deep).

The findings indicate that even if trawlers and fishing companies agreed to land all the red snappers, grounders, flatfish, and seatrout, which account for less than 3% of the total catch, it would mean an increase of 300–1000 t/year of first-rate fish. They would have to be stored frozen on board, under the most favourable conditions.

Such an agreement would be very profitable: it would put trawlers to greater use; it would cater to an existing market; and it would entail no major alteration in trawler or land-based storage installations. The government authorities could implement a new regulation that binds companies to an agreement when they renew their licences.

In addition, there are some species in the by-catch that are not kept at present but that are immediately marketable. They constitute roughly 9% of the total catch and could constitute about 3000–5000 t/year. Preservation of this category of by-catch, however, would necessitate a change in trawler management and design. Indeed, the fragile, small species, which would have to be properly prepared and stored on board, would weigh twice as much as the headed shrimp — roughly 6000 t/year.

The potential from this group of fish could be realized only if there were significant economic incentives. Because the domestic market is saturated with high-grade fish from the coastal waters of French Guiana, export trade could be expanded to the French West Indies, which is always looking for fresh fish of this type (from 2000 to 3000 t/year). Because the populations have a comaratively high standard of living, they can afford to give companies and factories a good purchase price.

Finally, there are all the other species in the by-catch that are currently unmarketable. They represent about 20 000–30 000 t/year. Little attention has been given to the possible utilization of this category of by-catch in French Guiana because the population is relatively small (60 000 inhabitants). Any research into the landing, preservation, and storage of this by-catch should only be undertaken if there is a proven requirement for the animal protein and, thus, a feasible market.

Because there is now no real problem of undernutrition in the French areas, particularly if great quantities of fish can be exported to the West Indies, it would be best to study how adequate amounts of fish-based flour could be produced in French Guiana at prices that will appeal to fishing companies and that will be competitive on the world market, that is to say with neighbouring countries.

The ideal solution to the problem of shrimp by-catch at present is to reduce the quantities of fish caught through regulations on seasons and gear and to offer incentives to shrimp operations to land marketable fish. To achieve this end, it will be absolutely necessary:

- To increase the number of scientific cruises because they alone can provide reliable data on shrimp and by-catch landings per area;
- To study the problems relating to the selection and regulating of trawler engines, and gear;
- To improve the existing technology with regard to the preparation of fresh fish on board; and
- To establish procedures for the production and transport of fish-based flour in tropical areas.

Guatemala

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This paper presents the experiences from Guatemala in the utilization of unmarketable by-catch for the production of fish soups and seafood chowder. The benefits and problems are described.

To increase the availability of protein sources for its population, the government of Guatemala set up Programa Integrado de Cooperativas Pesqueras del Pacífico (PICPA), which comprises five production cooperatives. These cooperatives have formed a federation (FEDEPESCA) to obtain services and to market their products jointly through Central de Servicios Pesqueros y de Mercadeo (CSPM).

The government granted a loan to each of the organizations to build vessels and to create the necessary infrastructure for the operations of CSPM. Thus, each cooperative operates a shrimp trawler (~15 m long) and a boat (~12 m long) for catching sharks. The CSPM has unloading facilities in the harbours on the Pacific coast and marketing facilities in the capital. The Pacific coast of Guatemala is sandy and well suited for shrimp fishing but not rich in high-quality fish. The cooperatives' vessels normally make 3-day trips.

Of the cooperatives' total production, 70% is low-value fish species caught during shrimp-trawling operations. As these species, which are small and unknown to the public, are difficult to market, even at low prices, quotas were imposed on the cooperatives' trawler ships.

However, Compañía Industrial de Alimentos (CINDAL), a subsidiary of Nestlé, was interested in the use of the fish as a source of protein. It manufactures soups, among other products, for the entire Central American region in its factory located in Antigua, 40 km from Guatemala City, but had found it necessary to discontinue production of the dried fish soups and seafood chowder because of the high cost of a protein concentrate, imported from France, for use in the soups.

A 1-year contract was signed between CINDAL and FEDEPESCA for the delivery of 120 t of fresh, headed and gutted fish, at $1.04/kg, deliveries to be made once or twice a week. CINDAL also agreed to accept, at the same price, unlimited quantities of shrimp heads, crab, and alacran shrimp (unmarketable species).

The contract means a stable source of income for FEDEPESCA, which makes a profit of ~ Quetzel 0.09/kg without risks on very small fish and unmarketable surpluses. The cooperatives benefit from the sale of small fish and shrimp heads. The country as well benefits from the utilization of a national resource previously wasted, the creation of 10 jobs in the heading and gutting process, and earnings in hard currency from exports of CINDAL soups to the rest of Central America.

However, some problems were encountered. The shrimp heads, crabs, and alacran shrimp do not keep long and are difficult to remove from ice. Also, delivery of the fresh, headed, gutted fish has proved difficult at times. It requires perfect coordination between FEDEPESCA and CINDAL, which uses the same machinery for the manufacture of other varieties of soup. In fact, difficulties in coordination have at times resulted in an accumulation of fish in FEDEPESCA's storage rooms and led to a decision to salt and dry the fish. This decision was considered particularly suitable because the odour of dried fish is stronger than fresh fish and increases the flavour in the soups. However, the obstacles — the difficulty in avoiding oxidation of fats in the fish during certain periods; the cost of salting and processing; problems of storage during the rainy season; unavailability of capital; and increased insect infestations — offset the benefits from the use of dried, salted fish and forced it to be abandoned except as a last resort. The experience of the cooperatives has been instructive and has been monitored by Guatemalan shrimp firms, as their operating costs have risen rapidly because of increases in oil prices.

Guyana

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As the Guyana by-catch project prepares to expand production to an industrial scale, a look at the initial stages of the project, the problems that were faced, and the way it evolved is worthwhile. Producing quality foodstuffs has always been the aim of the project, and the changes in consumers' attitudes toward fish, especially shark, are a sign that the project has succeeded.

In the 1970s, the Guyanese government became concerned about the viability of the shrimp industry as well as the recovery of the by-catch being dumped. It met with shrimp-vessel owners, and the two groups agreed that each trawler would land 1 t of edible fish for each shrimp trip in return for the removal of an export tax and a nominal payment from the government. The quantity was to be made up of selected species from the catch of the last 3–4 days at sea. The trawlers began reluctantly to land the by-catch, which was subsequently delivered to the government's embryonic fish-processing plant.

The first hurdle was to devise a method to separate the fish from the shrimp and, thus, to alleviate the concern of captains and crews that the presence of the fish was damaging their shrimp. Packing of the shrimp in polyethylene bags was introduced. The fish were to be washed and air freeze-dried in the passageway of the hold before storage.

When landed at the docks of the various companies, the fish had to be collected and transported to the processing plant operated by the government. No vehicles were available for the regular transport of the fish, no schedule existed for the arrivals of the trawlers, and invariably the quantity delivered was not 1 t but 5–7 t.

Because of the ad-hoc nature of fish deliveries, processing could not be streamlined. Further, the plant was operating with staff who were employed on a day-to-day basis.

The manufacture of salted–dried and smoked fish from indigenous species was begun without product-development work. As a result, the quality of the final product varied considerably, and consumers were unwilling to purchase the products.

These problems, as well as the rationale for the efforts, attracted the attention of the IDRC of Canada and were the basis for a project to develop ways of using the by-catch more effectively: in cheap foods suitable for distribution initially throughout Guyana and ultimately throughout the Caribbean. The achievement of this goal would increase the amount of protein available to the population as well as save on foreign exchange through the reduction of imports.

Specific objectives of the first phase of the project were to:

- Assess the abundance and species composition of the available resource;
- Study existing marketing and consumption patterns for imported fish;[1]
- Develop low-cost products such as salted, smoked, minced, and pickled fish;
- Develop high-value products in fresh, frozen, and canned forms;
- Develop miscellaneous products such as ready-cooked and boiled fish, fried fish, canned anchovy-like products, vegetable products, and soup mixes;
- Develop recipes and publications for the promotion of the new products; and
- Develop standards and techniques for quality control.

Work in product development focused on product substitution and product replacement, with particular emphasis on products that were either simple to process, cheap to store, or convenient to use. The investigations were influenced by traditional tastes and customs as well as the particular (and sometimes peculiar) local-market conditions. Dried, salted fish; smoked fish (hard and soft); pickled fish; dried, salted mince; fish paste; fish sausage; fish jam; and canned fish were

[1]Importation of fish products into Guyana has now been banned.

studied. In-house sensory evaluation, consumer acceptability, promotion, and education sessions were conducted in step with the product-development work.

Promotion and Marketing

Initial consumer acceptability trials took the form of tasting parties, scheduled for lunch time and catering to about 150 persons invited by means of a notice in the newspaper. A recipe for each dish was made available to as many visitors as possible. The results of the initial tests were generally favourable. However, they did indicate the need for changes in textural characteristics of some of the products. Equipment used in the preparation of dishes was standard for most kitchens in the area.

Efforts at consumer education revolved around the Kingston plant. Periodically, groups of about 20 consumers were invited to tour the plant and observe the production lines. At the end of the visit, the groups were invited to sample a few dishes prepared by the test kitchen and were given recipes to take home.

The products were promoted at both special-invitation luncheons with themes, such as "Fish for Christmas" and "There's more to fish than frying," and less-elaborate luncheons open to the public.

A significant achievement of these consumer-oriented exercises was the change in attitude to one fish in particular — shark. When the project started, the demand for shark or any of its products was extremely low; now, a large number of consumers specifically ask for it in dried, salted form.

In 1980, the Caribbean Community (CARICOM) Secretariat collaborated with project personnel sponsoring a study on consumer attitudes to fish and fish products. Among other things, the study sought to:

- Identify consumer attitudes to fish and fish products;
- Develop attractive and appropriate packaging for retail presentations of selected fish products; and
- Determine consumer acceptance of the products developed by the project.

The study was conducted in Antigua, Barbados, Grenada, Guyana, Saint Lucia, and Trinidad and Tobago. The findings were promising. The meal-eating behaviour of consumers in these areas indicated clearly that fish is a dietary staple — either first or second choice among sources of animal protein for the midweek meal. Fresh fish was preferred, followed by salted fish. The significance of these findings was that they showed potential not only for the domestic market but also for the export market. One can surmise that the major product — salted fish — could create a sound reputation and open up markets for other products such as fish cakes, fish sausage, and fish pâté. The potential is immense but can only be realized by a sound and versatile production unit.

Small-Scale Production

The need to provide consumers with a variety of food products forced the commencement of production before any significant results were obtained through research and development. In 1972, a portion of a building, which was formerly an animal-feed mill, was made available for initial production efforts. This building was used until 1975 when it was closed for reconstruction into the Kingston Research and Development Centre.

Then, fish were channeled to the processing lines primarily by size. In general, small fish such as *Macrodon ancylodon* (bangamary) and some *Micropogon furneri* (croakers or double-belly basha) were selected for smoking or pickling, and larger fish like *Cynoscion virescens* (trout) and some croakers and *Carcharinus* sp. (shark) were to be salted and dried. The *Caranx hippos* (cavalli or cravalle) was also used as raw material for smoking because of its characteristic dark flesh.

The fish to be smoked were gutted but not headed; the backbone was not removed. The exceptions were the cavalli, which were filleted. The dressed fish were placed in a saturated brine for 2–3 days, then removed, drained, and placed in the smoker. They were smoked for 8–10 hours, after which they were ready to be marketed, the salt content being about 14% and moisture content about 40%. The smoking temperature was about 45°C — low enough to avoid cooking the fish. Smouldering softwood sawdust was used to generate the smoke. The smokers were locally designed and constructed.

At first, the fish to be dried and salted were cured in a modified "gaspé" cure method. In this method, the dressed fish are placed in brine with alternate layers of salt for 4–5 days. They are then stacked or piled for 1–2 days before being dried. Later, the "kench" cure method was introduced. Here, the dressed fish are packed on stands with alternate layers of salt. The juices from the fish are allowed to drain away. After 2 days, the pile of fish is restacked so that the upper layers are at the bottom and vice versa. After a further 2 days, the fish are removed from the pile, and the adhering salt is brushed off. The fish are then dipped briefly into water before being dried.

In the early days, drying was artificial: a direct-heated, hot-air dryer at a temperature no higher than 45°C. Later, a locally constructed indirect-heated, hot-air dryer was used. Its use was discontinued after a short while, however, because of its poor design. Sun drying on covered racks was the next method used, and a greenhouse-type solar dryer is currently being tested. However, mechanical dryers and smokers seem to be needed to stabilize the operation.

Several simple-to-process products were introduced to the market either through the outlets at Guyana Fisheries Ltd or through the leading supermarkets. Among the products were fish fillets; frozen fish blocks; fish steaks; whole, dressed fish; and whole round mixed fish. The size of the fish influenced the end-product. For example, larger fish like *C. virescens*, *Epinephelus tauvina* (grouper), or *Lutjanus aya* (snapper) were filleted or made into blocks or steaks, whereas small fish such as *Nebris microps* (butterfish), *M. ancylodon*, or *M. furneri* were sold butterflied, whole dressed, or as mixed fish in the round. Prices ranged from G$0.45/lb. ($1.00/kg) for mixed fish in the round to G$3.00/lb. ($6.50/kg) for snapper steaks.

In addition to these standard and traditional products, some convenient commodities were developed and produced on a limited scale. Hot, smoked fish were marketed as breakfast fillets. A smoked fish pâté, margarine, local seasonings and spices, and a fish sausage were also developed (Table 1).

Table 1. Quantities (kg) of foodstuffs produced by Guyana Fisheries Ltd.

Fish product	1978	1979	1980
Processed (primary products)	127372	168334	347475
Dried, salted	27273	59013	74168
Smoked	34091	19113	29545
Pickled	22727	2597	2627
Minced	–	17925	–
Paste	–	1167	1898
Sausage	–	–	940

Two important constraints to the production efforts were, and still are, the lack of a steady, uniform supply of raw material and the lack of sufficient production capacity.

Planning for Expansion

A number of factors influence plans to expand the current level of operations. Among these are the collection and handling of the by-catch; continued research and development; quality control; equipment; consumer promotion; and management. Currently, the by-catch being landed represents the harvest of the last 3–4 days of a shrimping trip. Yet, the trawlers are at sea for about 30–35 days. A system that can conveniently collect the earlier harvest of incidental catch has yet to be developed. Various suggestions have been made, including the use of collector vessels and floating rafts with marker bouys. Sponsored by the CARICOM Secretariat, a Canadian consultant group is at the moment evaluating the alternatives with a view to identifying the most feasible.

Research and development in methods of harvesting, processing, and marketing need to be continued, as do efforts to standardize processes for industrial-scale production. A spinoff activity would be the refinement and continued development of nonfood products such as shark leather. Applying the results of development work depends on appropriate equipment, some of which may have to come from outside Guyana. Recently, Guyana Fisheries Ltd acquired a range of equipment to boost its production capability.

To date, the consumer promotion and education exercises have played a major role in increased utilization of fish and fish products in Guyana. A critical aspect of this work is recipe development, demonstration, and dissemination. As activity on product development and production increases, consumer promotion programs will be tailored to acceptability and utilization.

All of these facets of the expansion program need to be coordinated and directed by an innovative and dedicated team. Unless the various elements are effectively managed and executed, the potential utility of the resource — the shrimp by-catch — will not be realized. To date, despite various obstacles, significant achievements have been recorded. I believe that this pattern will continue.

Sabah, Malaysia

Datuk Chin Phui Kong *Department of Fisheries, Sabah, Malaysia*

Demersal catch by the shrimp trawling operations of Sabah, Malaysia, totaled 2.7×10^4 t in 1979, comprising 5.4×10^3 t shrimp and 2.1×10^4 t fish. Fourteen groups of fish are considered most important in the by-catch, which consists of more than 100 species. Until very recently, a considerably large portion of the fish by-catch was discarded at sea, 57.4% being discarded in 1979; 26.1% was sold fresh for human consumption, 8.5% was processed into fish balls, cakes, or salted, dried products. The remainder was used in animal feeds (5.9%) and fertilizer (2.1%). Increasing amounts of by-catch are being used as feed for fish and prawns in the newly developed aquaculture projects. The amount of "trash" fish required for these projects is estimated, within 10 years, to be greater than the amount currently landed.

The coast of Sabah state, Malaysia, stretches about 1500 km and houses more than two-thirds the population, including some 15 000 people who derive their living from fishing. In 1979, 4600 motorized fishing boats operated along the coast, and, of these, 800 were shrimp trawlers. Shrimp trawling is the most important fishery in Sabah. It began in 1960 when the otter-trawl fishing method was used successfully in Sabah waters. The shrimp catch since has increased from 930 t in 1963 to 5430 t in 1979 (Chin and Goh 1967; Malaysia, Department of Fisheries 1980).

Although bottom trawling has proved to be the most efficient method for catching shrimp in Sabah, it also unselectively catches great quantities of fish. The fish by-catch, on average, forms more than 80% of the total catch by weight, and its disposal has always posed a difficult problem.

In 1979, total catch by shrimp trawlers was estimated to be about 2.7×10^4 t, the by-catch being 5.7×10^3 t, 12.4×10^3 t, and 3.2×10^3 t in the west coast, northeast coast, and the southeast coast, respectively. The fish/shrimp ratio was highest in the waters off the southeast coast (6 : 1). Thus, the amount of fish caught by shrimp trawlers in that year was 21 250 t.

Although more than 100 species of fish are caught by shrimp trawlers in Sabah waters, there are 14 important groups of commercial fish. These are unprocessed and sold fresh in the fish markets for human consumption, especially to the people living in the remote interior. They comprise threadfin bream (*Nemipterus* spp.), trevally (Carangidae), grouper (*Epinephelus* spp.), croaker (Sciaenidae), grunt (*Pomadasys* spp.), white fish (*Lactarius lactarius*), red snapper (*Lutjanus* spp.), goatfish (*Upeneus* spp.), mackerel (*Rastrelliger* spp.), small barracuda (*Sphyraena obtusata*), flathead (*Platycephalus* spp.), halibut (*Psettodes erumei*), hairtail (*Trichiurus haumela*), slipmouth (Leiognathidae), and lizard fish (*Saurida* spp.) (Bin Sam Abdul Latiff et al. 1976; Bin Sam Abdul Latiff 1979).

Almost all species in the fish by-catch are edible; however, the blowfish (Lagocephalidae) are considered poisonous. The tripod fish (Triacanthidae), the cardinal fish (Apogonidae), and commercial species that have not attained marketable size (12 cm) are usually not marketed for human consumption.

Owing to the limited storage and ice available on board the vessels, shrimpers discard most of the low-value commercial fish, irrespective of size, in the first 2 days of a voyage, in addition to the nonmarketable fish, and only retain those of high value. However, they try their best to save the entire fish by-catch on the last day of fishing, especially that of the last haul, for marketing. Thus, the "trash" fish that appear at the fish markets are usually small, but those that have been thrown overboard at sea, which constitute the greater portion of the catch, are all sizes.

Sabah has gone through various stages of shrimp-trawling development in the past 20 years. On this 21st year of the establishment of this unique industry, shrimpers can look back with a sense of pride that they have now mastered the techniques of catching shrimp and can look forward to proceeding further afield in future. Unfortunately, the techniques for processing and marketing the fish by-catch have not developed along with the shrimp industry.

Of the total 2.1×10^4 t of fish caught in shrimp trawling in 1979, about 1.2×10^4 t or 57.4% were discarded at sea. The rest were marketed fresh for human consumption (26.1%), made into fish balls, fish cakes or salted, etc., for human consumption (8.5%), marketed fresh for animal feeds (5.9%), or used as fertilizer (2.1%).

Owing to the rapid increase in the urban population, the consumption of fresh, unprocessed fish in the cities has risen steadily in recent years. The same is true in rural towns, and, aided by the improvement of road transportation, the sales of fresh fish have increased many fold.

The marketing of fresh fish in Sabah is carried out mostly by individuals or the so-called fishmongers. Their business activities are centred at markets, which are built by the government. Every city or town has at least one fish market, which is, in the case of coastal towns, always at the waterfront.

Wooden boxes, lined with foam plastic or styrofoam for insulation, are extensively used by fishmongers to keep fresh fish. When the day's supply is greater than the demand, the excess fish are stored in crushed ice in the insulated boxes in the markets. The boxes are also used for delivery of fresh fish to the rural centres, 100–250 km away. The holding capacity of these boxes ranges from 120 kg to 300 kg. In most cases, light trucks are used for transport, each truck carrying 1–3 boxes. The driver is often the owner of the cargo. This fresh-fish marketing network has so far been serving the rural communities quite satisfactorily, and indications are that it will expand whenever there are new marketing outlets. Prices of fresh fish vary, depending on the supply and demand and the grade of fish. In 1979, top grade fish sold for U.S.$1.37–2.48/kg, and "trash" fish, U.S.$0.06–0.20/kg. The two intermediate grades of fish ranged from $0.34/kg to $1.62/kg.

Fish balls and fish cakes from the by-catch primarily incorporate conger eel (*Muraenesox cinereus*), lizard fish, hairtail, threadfin bream, shad and herring (*Ilisha elongata* and *Opisthopterus tardoore*), croaker, and sharks.

The flesh is extracted either by hand or by mechanical separator. Normally, the species are mixed together, and other fish, such as yellowtail (*Caesio* spp.) and Spanish mackerel (*Scamberomorus* spp.), which are not normally caught by the shrimp trawlers, are often added for improved quality. Each manufacturer has a secret blend.

Recent processing trials on fish balls, conducted by the Department of Fisheries, indicated that two species of fish in the by-catch, *Leiognathus splendens* and *Pomadasys hasta*, which had not been used by commercial processors, could produce fish balls of moderate quality. Catfish (Ariidae) were also tested but were found to be unacceptable (Snell 1978a,b); when salted and dried, however, they sell well in local markets. They are split, lightly salted in brine, and sun dried. This process has proved appropriate for croakers as well.

More "trash" fish are used for animal feeds now than were used 2 years ago because of the development of intensive culture of prawns (or shrimp) in brackish-water ponds and marine fish (grouper, snapper, and sea perch) in floating net-cages. These two newly developed systems of aquaculture are heavily dependent on "trash" fish as feeds. A floating net-cage farm holding 60 000 fish is estimated to consume 200 t of "trash" fish annually. A 60-ha prawn-culture farm in Tawau at present consumes 1.5 t of "trash" fish each day, and, when the farm has completed its development target of 800 ha of ponds, its daily need will be 20 t or 7.3×10^3 t/year, which is more than double the total fish by-catch for Tawau in 1979.

Several large-scale commercial prawn-culture projects are now being implemented in Sabah. When these projects are completed and operational, the amount of "trash" fish required by the projects will probably exceed the amount available, consuming the entire fish by-catch from shrimp trawling. Thus, the entire yearly fish by-catch may be utilized within the decade.

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Mexico

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This paper summarizes the present national perspectives for the full utilization of shrimp by-catch in the production of high-value protein at low cost. It discusses biotechnological issues, technological alternatives developed in laboratories, pilot plants, and industrial plants for the utilization of by-catch. Finally, the most important perspectives for the utilization of by-catch for direct human consumption are set out.

Population growth in most developing countries requires government intervention into the use of natural food sources to solve the problem of feeding people. In Mexico, the dietary needs of more than 70 million people have to be satisfied. The fish resources of the country have not been fully utilized to date because the efforts of the fishing industry have concentrated on shrimp for more than 30 years, despite some efforts to develop fisheries such as anchovy, sardines, and tuna in the early 1960s.

Since 1977, the federal government has been promoting greater use of fish resources, introducing new products made from species previously wasted. The Department of Fisheries has played a significant role, manufacturing new products from minced flesh of by-catch fish.

When the first samplings of shrimp by-catch were done (1955 and 1956), all the by-catch was being discarded immediately after the shrimp had been selected and stored in the holds. Thus, on both Mexican coasts, huge volumes of shrimp by-catch have been jettisoned to the sea for more than 25 years. The magnitude of this problem is clear when one considers that the fleet now comprises more than 2600 vessels.

Utilization of the by-catch depends upon finding answers to many questions, including: How should by-catch be kept on board? Which species of by-catch should be kept, and what should their volume be? Who is going to purchase the by-catch? How do crews and owners benefit? What products can be made from the by-catch? And how can marketing problems be solved? At present, the federal government is seeking answers to these questions so that it can formulate a policy on the use of by-catch in Mexico.

Objective

Thus, the Department of Fisheries undertook to submit technical proposals for the use of the by-catch in the manufacture of products for direct human consumption. The proposals had to allow for the fact that the by-catch comprises three categories of fish:

- Large fish of high consumer demand that, after being cleaned and washed, are frozen and marketed directly;
- Small, edible fish not used for direct human consumption but having enough flesh, when cleaned, washed, and mechanically deboned, to produce mince for use in many products; and
- Very small fish or those having a high number of bones, difficult to eviscerate by hand or to fillet, and fish that do not comply with strict health regulations and cannot be used for direct human consumption.

Since the work was initiated, pilot plants have tested the use of small by-catch species (10–15 cm) in the production of dried, salted products (cakes, minces); sausages; pastes (pâtés); frozen products (hamburgers, bars, balls, etc.). Species longer than 20 cm are sold fresh.

At present, the fish by-catch is being used for industrial manufacture of Pepepez, a product moulded into the shape of a fish, breaded, and frozen. This product is manufactured by the government-owned fishing plant, PROPEMEX, and is marketed in the larger Mexican cities.

Methods

The first step was to divide the Gulf of Mexico and the Pacific into zones so that the relative volume and composition of the by-catch could be determined as well as the sizes and weights of organisms caught during fishing trips (2–15 days). Trawls from vessels were sampled — the shrimp and by-catch being weighed — and the number of tows, the geographical location, and the trawl depth were recorded. The samples were kept on board and later were classified by species, measured, and weighed. Instruments used were a 0–50 cm ruler and a Yamato 0–200 g scale.

The most important species were headed and gutted by hand, comminuted, and subjected to bromatological analysis in the laboratory by technicians involved in the research project. This analysis was used in determinations of the chemical composition of the organisms present in the by-catch.

Results

Sporadic biologic samplings of the by-catch in different areas along both coasts of Mexico indicated the presence of many species of fish, crustaceans, molluscs, echinoderms, etc. The relative composition varies according to the fishing area, depth, season, and even type and characteristics of the vessel. Fish composes 60–64% of the by-catch; the remainder is crustaceans, molluscs, and echinoderms. In the Gulf of Mexico, the main species of fish in the by-catch average 15 cm and 60 g.

The efficiency in heading and gutting this size fish was about 50 kg/hour/worker, and yield was about 60% of initial total weight. The yield of mince from gutted, cleaned fish was about 70%.

Bromatological analysis of the mince from the main species of fish indicated that protein was 17.8%, fat 3.4%, ash 1.6%, and moisture 77.9%.

Discussion

In 1979, shrimp catches in Mexico totaled 30 781 t. As the shrimp/by-catch ratio in our waters is 1 : 5, potential raw material from by-catch was estimated at 1.54×10^5 t. This would yield about 4.2×10^4 t of mince for the manufacture of food products for direct human consumption.

White-fleshed, lean fish are the most suitable raw material, as fatty fish become rancid and change colour during storage. As the fish have to be gutted before being ground, product costs depend on the size of the fish.

Conclusions

The studies have shown that the by-catch is mainly composed of fish of low fat content, acceptable both for direct human consumption and for the production of high-quality protein concentrates for inclusion in other products. The use of minced fish as a protein ingredient in processed meat products is promising, for it enhances appearance and increases nutritional value. However, the potential for mince depends largely upon the capability of the food industry to manufacture high-quality products using specialized machinery.

The quality of the finished products is ultimately dependent on the quality of the raw material. Fish must be preserved on board the vessels in holds that are either filled with ice blocks or refrigerated. Sometimes, heading and gutting on board will be required.

Recommendations

Technical and economic analyses to determine profitability of an industrial project on a national scale are a priority. Any project to use the by-catch should be economically attractive both for the shrimpers and for the manufacturers.

Another priority is the introduction of fishing regulations to control granting of licences and unloading of by-catch because, among other reasons, the shrimp are being transported to markets elsewhere by exporters who avoid taxes by transshipment of the catch on the high seas.

Mozambique

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The government of Mozambique has only recently turned its attention to the vast waste of the by-catch from shrimp-trawling operations. Some preliminary studies have been undertaken to discover the size, species composition, and processing possibilities of the catch, but additional information is sorely needed. It is believed that there is an established market for any fish products in the country.

Mozambican catches of shallow-water shrimp are 1.0–1.2 $\times$ 10^4 t/year. An estimated 1000 t of by-catch are landed, but exact figures of the by-catch discarded are not available. A preliminary survey and data from commercial vessels show that shrimp/by-catch ratios range from 1 : 3 to 1 : 1 according to season, fishing gear, and company. Estimated at 2.0 $\times$ 10^4 t/year, by-catch could result in a 50% increase in the annual registered landings of marine fish.

The existing space on the fleet trawlers seems to be one of the major limiting factors to a more rational utilization of the by-catch. Further studies should concentrate on the exact magnitude and composition of the by-catch and on the technological requirements for its utilization. No major problems are expected in marketing of by-catch. The bulk could be transformed into a salted, dried (eventually minced) product.

Shallow-water resources are predominantly located near the Sofala Bank, which extends from Mambone in the south to Angoche in the north. It covers 39 000 km^2 of 10–15 m deep water and an additional 8360 km^2 of 50–200 m water. Small stocks of shrimp can also be found in the Maputo Bay. The most important species in these shallow waters are: *Penaeus indicus* — white prawn; *Metapenaeus monocerus* — brown or ginger prawn; *P. japonicus* — flower or banana prawn; and *P. monodon* — tiger prawn. Species composition varies within the year and from year to year. The average is 45% white prawn, 45% brown prawn, and 10% tiger prawn and flower prawn. Deep-water shrimp found in the southern area, at 280–550 m depths, could yield about 4000 t. The predominant species is *Hymenopenaeus triarthrus*, the pink or knife prawn.

Vessels from Mozambique have been fishing for shrimp since 1965. Catches of shrimp are about 1.0–1.2 $\times$ 10^4 t/year, and 60% of the catch is taken in the first 6 months. Collection of data began in 1978. The shrimp fleet, the only industrial fishery in Mozambique, comprised 72 vessels at the end of 1980: 34 belonged to the national fleet and 38 to joint ventures. The majority are double-rigged trawlers, 100–200 t.

Of the six fishing companies, two have land bases in Beira, two in Quelimane, one each in Angoche and Maputo. The Quelimane and Angoche companies are shipping their shrimp catches to Beira for export. Average catching rates for the EFRIPEL company shrimp-fishing vessels varied from 50 to 90 kg/hour in the last 5 years. Information on yearly by-catch is scarce. One survey was carried out for 2 months by a research vessel, and comparable data were obtained from the EFRIPEL vessels in the same area. The research vessel with catching rates >50 kg/hour obtained a shrimp/by-catch ratio of 1 : 3. At a lower catch rate, the ratio was 1 : 12. Comparable data from EFRIPEL vessels were a shrimp/by-catch ratio of 1 : 1.5 when the catch rate was <10 kg/hour and 1 : 0.7 when the catch rate was >50 kg/hour. Both research and EFRIPEL vessels worked with trawls 17 m wide and at a fishing speed of 3 knots, but horizontal opening varied considerably — the commercial vessels worked with a 2-m opening and the research vessel with 7-m. Other companies estimate that the yearly shrimp/fish by-catch ratio is 1 : 3.

Data from the research vessel showed that pelagic species were as abundant as demersal species in the southern areas, whereas demersal species dominated by 56–63% in the central and northern areas. Sharks and rays represented 2–4% and nonfish species (squids, cuttlefish, and crabs) 2.5%. Nine families formed 75% of the demersal fish catch. Croakers, grunts, lizard fish, goatfish, and catfish were the most important. Four families accounted for more than 80% of the pelagic fish catch. Ponyfish dominated in the northern areas, anchovies and sardines in the southern areas, and jacks, scads, anchovies, and sardines in central waters.

During 1980, only 950 t of by-catch fish were landed with 7000 t of shrimp. Most companies are reluctant to bring in their by-catch, claiming that labour-intensive operations during the season and limited freezing and cold-storage capacities inhibit further utilization of the by-catch.

The government's policy to resolve the domestic-fish shortages is based on efforts to maximize the use of shrimp by-catch. With an estimated marine-fish catch of $3.0–4.0 \times 10^4$ t/year and an average shrimp/consumable fish ratio of 1 : 2, registered landings could be increased by 50%. An economic and technical analysis should be made on the structure of the existing shrimp fleet of freezer trawlers, considering seriously the possibility of trawlers with ice-carrying capacity operating from ports with land-based processing facilities. In this context, technical aspects, such as shipment on high and sometimes rough seas and type of fish storage systems, should be studied in more detail. Experiments are under way to reorganize the shrimp fleet into groups of 4–5 seagoing boats operating with carrier vessels. The bulk of low-value fish could be transformed into a salted, dried, and eventually minced product. Traditionally large consuming areas for this product are located in the centre of the country, and no marketing problems are expected in the short term. At present, studies that result in action programs for better shrimp by-catch utilization and that take into consideration the lack of refrigeration capacity, space, and personnel on freezer trawlers have a high priority.

Sri Lanka

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In Sri Lanka, the Institute of Fish Technology has begun making food products from shrimp by-catch, which in this area primarily comprises silverbellies. The products include fish sausages, fish paste, and a dried, salted mixture called sambol. To date, consumer acceptance has been encouraging.

Shrimp trawling is carried out in the northern and northwestern coastal waters of Jaffna and Mannar and in the shallow waters of Palk Bay, Mannar Gulf, and north of Adams Bridge. These waters rarely exceed 15 m deep, and their soft, muddy bottom is suitable for prawn trawling. Fish yields vary from 225 kg/hour (Medcoff 1963) to 1000 kg/hour (Berg 1971). More than 80% of the catch consists of small fish of low economic value — mainly silverbellies (Leiognathidae). The day and night catches vary in species composition, silverbellies being more abundant during the day and prawns during the night.

Of the total 1979 production of shrimp (3378 t), more than 60% was harvested from these trawling grounds. The annual by-catch is about 3.0×10^4 t. Because of limited storage facilities on the vessels, the economically valued fish are removed, and the rest discarded at sea. The fish that are landed go into the production of salted, dried fish or meal.

Based on productivity studies and catch-data analysis, a maximum sustainable yield of $5–10 \times 10^5$ t of by-catch could be expected from the 2800 km^2 of the continental shelf that is suitable for shrimp trawling. The silverbellies — the major part of the catch — are not economically valued because of their sharp, hard bones and their perishability — a reflection of their high gut/body ratio and high sand content (~1.5% of body weight).

In Jaffna, shrimp landings amount to 1132 t and by-catch to 1.5×10^4 t, but about 1.3×10^4 t of by-catch fish are discarded. In the Mannar area, landings total 785 t shrimp and 1.0×10^4 t by-catch, but about 7×10^3 t of by-catch fish are discarded.

Thus, only 10–25% of the by-catch is commercially utilized. In Mannar, the by-catch is used by two area fish-meal plants that use about 3–4 t/day. The rest of the fish are salted and dried in the sun. Under bad-weather conditions, most of the by-catch is wasted because the fish-meal plants use only small amounts and the fish cannot be sun dried.

The Institute of Fish Technology, Ministry of Fisheries, is at present studying methods of utilizing available by-catch for human consumption. Research on product development seeks a reasonably priced fish product for the consumer and a higher return for the producer. Until such methods are developed, by-catch will go into the production of fish meal, which has a ready market in Sri Lanka. The Ministry has even taken steps to increase fish-meal production by 300% in 1982.

The Institute has begun work on a plant that will produce fish sausages, cakes, and fish paste from by-catch fish mince. The plant will be situated in a freshwater fish-processing complex (FPC) and the belly parts of the filleted freshwater fish will be mixed with by-catch fish mince to produce a range of fishery products. There are also plans to set up a 5-t FPC plant on the northwestern coast of the island. The Ministry is hoping to use two trawlers so fish supplies to the plant are uninterrupted. Test-market surveys have shown a ready acceptance of the finished product. Production of an FPC pilot plant that will use silverbellies is also in progress.

The fish mince is obtained with a flesh-and-bone separator and the mince cooked for a short time then dried in a cabinet until the water content is below 10%. There is no grinding or sifting required because the product is relatively free from bones. Packed in polyethylene, this product keeps for over 6 months at room temperature without deterioration. The consumers have accepted it, and it has been successfully incorporated into a variety of dishes.

Commercial-scale production of a savoury fish mixture, locally known as fish sambol, has begun in Mannar. The plant consumes silverbellies at a rate of 600 kg/day. The fish are cooked whole, and the fish flesh is separated manually, with care so that no bones are left in the cooked flesh. It is then spread on trays and hot-air dried at 60–80°C for 4–5 hours so that water content is reduced to 10–12%. Air-dried onions, chillies, citric acid, and salt are added to the dried fish. The finished product is marketed in polyethylene bags at Rs. 2.00/40-g pack ($0.10/40-g pack). A special 10-kV tunnel dryer was designed and manufactured locally at a cost of U.S.$3200.

Skates and rays are also caught in large quantities during certain seasons of the year. The fish are not very popular and are normally discarded at sea. These fish, however, in the filleted form, have been well accepted by consumers. Fish cubes made from dehydrated skate have also proved popular. Moderately high temperatures and wind action during air drying dispel the ammonia smell that makes the fish unacceptable. The dried product has the texture of smoked fish. Production on a pilot scale will begin in 1982. The Institute has also developed a formula for a dried-soup mixture and a stock cube prepared from silverbellies. The fish products that have been marketed are acceptable to the consumer, and efforts are now being made to introduce them for institutional use.

Thailand

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Fish by-catch in Thailand is increasingly being used for human consumption. One reason is that catches by the Thai fleet in neighbouring countries' waters have been curtailed by the declaration of 200-mile exclusive economic zones (EEZs), and efforts are being made to meet the demand that was earlier catered to by these catches. Other reasons are rising fuel costs and increased exports of prime-quality fish. Annual production of by-catch is about 8.5 $\times$ 10^5 t, or 43% of total production of marine fish in the country. Numbers of different species in this by-catch are great, and this fact complicates efforts to make use of it. At present, therefore, most of the by-catch is used for animal feed or fish meal. However, the government of Thailand has announced that it aims to develop postharvest technology to upgrade a portion of the by-catch for human consumption. It is expected that 1 $\times$ 10^5 t annually will be utilized in this manner. Various products have been developed at the Fishery Technological Development Division, Department of Fisheries, and those that have market potential are being followed up.

By-catch in Thailand includes a wide variety of small demersal fish. In the past 5 years, 40–53% of total marine production was landed by-catch (Thailand, Department of Fisheries 1979). At present, small pelagic fish are becoming more important because of the large quantities caught, 7–10% of total production. Only a small portion of these are utilized.

By-catch in the country during 1971–80 fluctuated from 6.2 $\times$ 10^5 t to 8.5 $\times$ 10^5 t. During the same period, the percentage of this catch converted into fish meal increased steadily from 46 to 99 (Table 1). Small pelagic fish, mostly *Sardinella*, increased radically from 1.1 $\times$ 10^4 t in 1972 to 2.1 $\times$ 10^5 t in 1977. The percentage of small pelagic fish converted into fish meal in the last decade was 20–25, although the figure for 1978 was 40%. Almost all the by-catch was used for animal feed, but small pelagic fish still have a possible use as human food.

Kuantanom (1978) investigated species composition of fish by-catch and found 36 families of young economic species and 35 families of unfavourable species. The respective percentages in weight were 33.29 and 66.71. The young, economic species were represented by 25 demersal fish families, 7 pelagic fish families, and 4 invertebrates. The unfavourable species comprised 32 demersal fish families and 3 invertebrates.

Postharvest Losses

Two categories of low-value fish are used in fish meal. The first category is by-catch from trawl fisheries, from which about 33% by weight could be utilized for human consumption if they had matured. The average length is 5–7 cm (Kuantanom 1978). About 67% by weight of the unfavourable species in this category could also be utilized if postharvest technology were introduced. The second category is small pelagic fish that are mostly *Sardinella*. At least 25% (4.0 $\times$ 10^4 t) of small pelagic fish are converted to fish meal. No data exist on the quantity of these fish used as feed by duck farms, but a large quantity of low-value fish are used for animal feeds.

Besides these losses, an estimated 4.0 $\times$ 10^5 t of by-catch are discarded annually at sea (Sumner 1976). However, incomes in the fishing industry are declining for many reasons, and the practice of dumping fish at sea is diminishing. The large vessels that go on long voyages discard almost all the fish caught at the beginning of the trip because the value of the fish does not offset the cost of ice to preserve them and space on board is limited.

Utilization and Processing of By-Catch as Human Food

For the past few years, the larger fish in the by-catch have been used in salted, dried, smoked, and minced products for human con-

Table 1. By-catch, small pelagic fish used for fish-meal production in Thailand (1971–80).

	Landings(t)		By-catch		Small pelagic fish	
Year	By-catch	Small pelagic fish	t	%	t	%
1971	655329	28804	304610	46.48	5671	19.69
1972	719091	11376	365880	50.88	2275	20.00
1973	804478	34285	458870	57.04	6857	20.00
1974	690270	58222	450297	65.24	11644	20.00
1975	634971	63522	507976	80.00	12704	20.00
1976	620646	105692	496516	80.00	21124	19.99
1977	836643	214077	690914	82.58	42815	20.00
1978	847412	145278	829131	97.84	58111	40.00
1979	784267	161890	769279[a]	98.09[a]	42999[a]	26.56[a]
1980	648750[a]	134955[a]	642262[a]	99.00[a]	33738[a]	25.00[a]

[a]Estimated figures.

sumption. Smaller fish have been in fish sauce, fermented fish, and fish paste. However, only small quantities have been used because of the poor quality and flavour of by-catch. Small pelagic fish are salted and dried but most often are canned. Quality of the products is mediocre at best because of improper handling.

The Fishery Technological Development Division (FTDD) is conducting applied research to develop several kinds of fishery products to utilize by-catch. The products that have been distributed for acceptability tests in limited areas are fish crackers, fish noodles, fish biscuits, fish-protein concentrate, dried mince, and some canned goods.

FTDD also is cooperating with IDRC and FAO to carry out projects on fish processing and utilization with the objective of increasing utilization of low-value fish.

The IDRC-funded fish processing project undertaken by FTDD has been focusing on production of a popular food called lukchin pla (fish ball), which is made from minced flesh. In 1978, SRG Industrial Limited estimated that there were about 40 fish-ball factories in Bangkok, producing more than 3.7 million balls annually and consuming 45 t of whole fish daily. The major problem encountered was the shortage of cheap fish as raw material. The industry, therefore, requested technical and economic advice concerning species available to them.

Good-quality fish balls are white, cohesive, and elastic, the flavour being sweet, fishy, and slightly salty. Only those that are prepared from expensive fish, such as Spanish mackerel and yellowtail, can meet these requirements. Most producers, therefore, accept a poorer quality, mixing a few species of cheaper fish in the product.

FTDD has been testing various species of by-catch and some species of low-cost freshwater fish for use in fish balls. Experiments have been carried out with fish in various stages of deterioration (fresh till spoiled), and

Table 2. Cohesiveness, colour, and flavour of fish balls.

	Cohesiveness	Colour	Flavour
By-catch			
Threadfin breams	Fair	White	Acceptable
Yellowstriped trevally	Fair	Off-white	Unacceptable
Flathead	Fair	White	Unacceptable
Gobies	Fair–good	Off-white	Acceptable
Flatfish	Fair	Off-white	Unacceptable
Cardinal fish	Poor	White	Acceptable
Lizard fish	Poor	White	Acceptable
Freshwater fish			
Tilapia	Good	White	Acceptable
Carps	Good	White	Acceptable

the characteristics of flavour, colour, and texture of the finished products have been determined (Table 2). The method of making the fish balls in the project is similar to that used in factories so that the producers do not have to change their behaviour. Freshness of raw material was measured by a pH meter, total volatile bases, and organoleptic assessment. Texture, flavour, and colour of finished products were evaluated by trained personnel. However, texture was also measured by the quantity of salt-soluble protein. A focus of this project is to determine whether any of these characteristics can be used as a guideline to select raw materials that result in fish balls with acceptable texture (Table 2).

By-catch can be stored in ice 9–15 days, whereas freshwater fish can be stored 23–36 days. Thus, the quality of fish balls produced from by-catch was lower than from freshwater fish. The percentage of extractable protein of freshwater fish was as high as 76 even for fish kept in ice for 36 days. Among the by-catch species, the percentage of extractable proteins in lizard fish was highest (Table 3).

Table 3. Percentage of extractable proteins in some by-catch and freshwater fish.

Species	Ice storage (days)	Extractable protein[a] (%)
Lizard fish	1	78.09
	15	75.41
Flatfish	1	62.71
	19	43.58
Flathead	1	65.28
	19	44.38
Tilapia	1	88.01
	7	91.35
	23	82.77
Carps	1	115.50
	11	102.37
	22	86.19
	36	76.49

[a]Extractable protein (%) = salt-soluble protein–N/ total protein–N × 100.

Fish Silage

By-catch use in fish silage has been considered promising in Thailand (Saisithi and Rattagool 1979). Feeding trials were carried out with fish silage as the main diet; the results were compared with those for fish meal and commercial feedstuffs. Silage was produced from by-catch with a mixture of sulfuric and formic acids (1 : 1). Sulfuric acid is less than half the price of formic acid and is produced locally. The product has a long shelf life if kept with 0.5% propionic acid (Rattagool et al. 1979). No significant changes occurred in the amino acids up to 21 days of storage.

The trials were with broiler chickens. Dried silage, boiled fish silage, and wet silage were compared with fish meal, basal feed, and commercial chicken feeds (Rattagool et al. 1978). The feed conversion ratios of basal feed and wet fish silage were higher than those for the other feeds, whereas growth rates were similar. The diet of boiled fish silage resulted in high mortality, whereas dried silage, fish meal, and commercial feeds seemed to be comparable. The price/kg of diets from dried silage was the lowest. The feed conversion ratios of commercial feeds were lower than that of dried silage, but the growth rate was higher after 8 weeks of trials. Organoleptic examinations showed comparable acceptability of chicken meat from animals fed silage, fish meal, or commercial feeds.

Trials with pigs compared fish silage with fish meal as a main diet. Both dried and liquid fish silage was used, and the liquid silage proved more convenient. Growth rates of pigs fed fish meal were higher for the first 7 weeks but declined later, whereas those for pigs fed fish silage steadily increased. The percentage of red meat was higher from pigs fed fish silage. The flavour of the fat and meat was not adversely affected in pigs fed silage.

The FTDD received support from TPI in September 1981 to establish a British Petroleum (BP) silage plant. Silage produced by the BP plant will be supplied to the Livestock Development Department for duck-feeding trials in December. Liquid silage should prove suitable for ducks as it did for pigs. The FTDD with the assistance of FAO cooperated with a small commercial vessel and fish-meal plant to produce fish silage on board. Operations will start in December, and plans are to utilize the silage through the pig-raisers cooperative. Members of the cooperative could absorb all output from a small-scale production. If the operation is successful, production may be introduced on large vessels that discard low-cost fish.

The Institute of Food Research and Product Development (IFRPD) of Kasetsart University, Thailand, with the financial and other support of FAO undertook the task of incorporating fish-protein concentrate (FPC type B-

Norway) and roller-dried fish (RDF-Denmark) into traditional Thai dishes and conducting acceptability tests for the new products. The tests included many recipes based on traditional Thai foods, using FPC and RDF as the fish ingredients. Testing was among low-income groups. On a scale from 0 to 10 (with 5 being fair), the traditional preparations averaged 8, the RDF preparations 7, and the FPC preparations 6. FPC has disadvantages of being sandy and dark.

Conclusions and Recommendations

The quantity of by-catch from shrimp trawling in Thailand is large, and the species composition varied. Therefore, it is not feasible to implement techniques for one or a few species in large quantities for human consumption. The average size of the by-catch fish is 5–7 cm, the result being that 99% of the by-catch that is utilized goes to fish-meal production. Measures should be taken to manage these resources so that the capture of immature, edible fish is minimized. One possibility is to control the sizes and numbers of the trawls. At present, the best way to make use of the by-catch for human consumption is to improve the quality of the raw material so that it is suitable for some traditional products such as fish sauce and fermented fish. New products such as roller-dried fish and fish-protein concentrate using by-catch as a raw material are promising.

Because by-catch fish are too small for sale fresh, the FTDD plans to develop new products such as dried, salted, and seasoned products. Such products, consumed as appetizers, are quite popular in Southeast Asian countries. Another possibility is to use small pelagic fish as a raw material for minced products.

The fuel crisis will improve the economics of fish-silage production because silage does not require energy inputs. The technical and economic feasibility of producing fish silage on a commercial scale needs to be tested. New products, such as roller-dried fish, fish-protein concentrates, fish silage, fish noodles, fish crackers, and appetizers are needed for marketing trials. New technologies to utilize unfavourable species and small pelagic fish to produce traditional products such as fish balls, dried, and salted products, etc. are also needed.

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Films

Fish by-catch. . . bonus from the sea, a 16-mm, colour film (28 minutes) produced by IDRC, demonstrates how Guyana has begun to use some of the by-catch fish that have been traditionally jettisoned into the sea by shrimp trawlers off the country's coast. The film shows a pilot plant in action, processing filleted, smoked, salted, and minced products, and illustrates how the use of the by-catch could dramatically increase protein intake in many areas of the developing world. It is available for purchase or loan from Communications Division, IDRC, Box 8500, Ottawa, Canada K1G 3H9. A handling fee for loans is required except for requests from libraries, institutions, researchers, and administrators in developing countries.

FAO has produced related films and 35-mm filmstrips (with written or tape-recorded commentaries) in the areas of training in, and popularization of, fish processing. In addition, FAO maintains a library of films produced by other organizations and has prepared annotated catalogues of the collection, providing information on the content and suitable audiences for the films. More information is available from the Fisheries Department, Fishery Industries Division, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy.